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# Results of the Nationwide Urban Runoff Program

## Volume I - Final Report

# RESULTS

# OF THE

# NATIONWIDE URBAN RUNOFF PROGRAM

December, 1983

VOLUME I - FINAL REPORT

Water Planning Division

U.S. Environmental Protection Agency

Washington, D.C. 20460

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## DISCLAIMER

## FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about environmental quality. The complexity of our environment and the interplay among its components require concentrated and integrated approaches to pollution problems.

The possible deleterious water quality effects of nonpoint sources in general, and urban runoff in particular, were recognized by the Water Pollution Control Act Amendments of 1972. Because of uncertainties about the true significance of urban runoff as a contributor to receiving water quality problems, Congress made treatment of separate stormwater discharges ineligible for Federal funding when it enacted the Clean Water Act in 1977. To obtain information that would help resolve these uncertainties, the Agency established the Nationwide Urban Runoff Program (NURP) in 1978. This five-year program was designed to examine such issues as:

- The quality characteristics of urban runoff, and similarities or differences at different urban locations;

- The extent to which urban runoff is a significant contributor to water quality problems across the nation; and

- The performance characteristics and the overall effectiveness and utility of management practices for the control of pollutant loads from urban runoff.

The interim NURP report, published in March 1982, presented preliminary findings of the program. This document is the final report covering the overall NURP program. Several specialized technical reports are published under separate cover.

# PREFACE

The Nationwide Urban Runoff Program (NURP) was conducted by the EPA and many cooperating federal, state, regional, and local agencies, distributed widely across the United States. The individual project studies, which were conducted over the past five years, were designed and overseen using a common technical team from EPA headquarters. This approach was taken to assure a desired level of commonality and consistency in the overall program, while allowing each individual project to specially tailor its effort to focus on local concerns.

The program has yielded a great deal of information which will be useful for a broad spectrum of planning activities for many years. Furthermore, it has fostered valuable cooperative relationships among planning and regulatory agencies. The most tangible products of the program are this report, the reports of various grantees (available under separate cover), and several technical reports which focus on specialized aspects of the program, its techniques, and its findings. In addition, a considerable number of individual articles drawing on information developed under the NURP program have already appeared in the technical literature and address specific technical or planning aspects of urban runoff.

At the time of publication of this Final Report, the main technical effort of the NURP program is complete; the field studies and the analysis of most of the resultant data are complete enough that the findings reported herein can be taken with confidence. However, there is still some work in progress to make certain details of the program available for future use. The products of this on-going work include:

- A summary database which is being compiled to make all technical information from the 28 projects available for review and use (DECEMBER 1985);

- A technical report which focuses on the program's studies and findings relative to detention and recharge devices (MAY 1984);

- A technical report on urban runoff effects on the water quality of rivers and streams (MARCH 1984); and

- A technical report on the effectiveness of street sweeping as a potential "best management practice" for water pollution control (MAY 1984).

This report and the supplementary technical documents identified above, supersedes the earlier NURP publication, "Preliminary Results of the Nationwide Urban Runoff Program," March 1982. Information presented there has been expanded, updated, and in some cases revised.

ACKNOWLEDGEMENTS

The Nationwide Urban Runoff Program was unusual in its large scale, covering a broad spectrum of technical and planning issues at many geographic locations. Because the program placed such emphasis on tailoring the results to support the planning process, it involved many participants - some from EPA, some from other federal agencies, and many from state, regional, and local planning agencies and other consultants.

The program was developed, implemented, and managed by the Water Planning Division, Office of Water, at EPA Headquarters, Washington, D.C. Principal contributors were: Dennis N. Athayde, Program Manager; and Patrice M. Bubar, Norman A. Whalen, Stuart S. Tuller, and Phillip H. Graham, all of whom served as Project Officers. Additional contributions from EPA personnel came from Rod E. Frederick and Richard P. Healy (Monitoring and Data Support Division), Richard Field (Storm and Combined Sewer Section, EPA Office of Research and Development), and many project staff in the various EPA Regional Offices.

As described elsewhere, much of the field work, water quality analysis, and data analysis was performed by the U.S. Geological Survey (USGS), under a Memorandum of Agreement with EPA. Both District Offices and National Headquarters participated actively. The contributions of Messrs. Ernest Cobb and David Lystrom are especially acknowledged.

Members of the project team which provided essential strategic, technical, and management assistance to the EPA Water Planning Division through a contract with Woodward-Clyde Consultants were: Gail B. Boyd, David Gaboury, Peter Mangarella, and James D. Sartor (Woodward-Clyde Consultants); Eugene D. Driscoll (E. D. Driscoll and Associates); Philip E. Shelley (EG&G Washington Analytical Services Center, Inc.); John L. Mancini (Mancini and DiToro Consultants); Robert E. Pitt (private consultant); Alan Plummer (Alan Plummer and Associates); and James P. Heaney and Wayne C. Huber (University of Florida).

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# CHAPTER 1
# INTRODUCTION

Rain falling on an urban area results in both benefits and problems. The benefits range from watering vegetation to area cleansing. Many of the problems are associated with urban runoff, that portion of rainfall which drains from the urban surfaces and flows via natural or man-made drainage systems into receiving waters.

The historical concern with urban runoff has been focused primarily on flooding. Urban development has the general effect of reducing pervious land surface area and increasing the impervious area (such as roof tops, streets, and sidewalks) where water cannot infiltrate. In comparison with an undeveloped area (for a given storm event), an urban area will yield more runoff, and it will occur more quickly. Such increases in the rate of flow and total volume often have a decided effect on erosion rates and flooding. It is not surprising, therefore, that at the local level the quantity aspect continues to be a principal concern.

In recent years, however, concern with urban runoff as a contributor to receiving water quality problems has been expressed. Section 62 of the Water Quality Act of 1965 (P.L. 89-234) authorized the Federal government to make grants for the purpose of "assisting in the development of any project which will demonstrate a new or improved method of controlling the discharge into any water of untreated or inadequately treated sewage or other waste from sewerage which carry storm water or both storm water and sewage or other waste ..." The Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500) signaled a heightened national awareness of the degraded state of the nation's surface waters and a Congressional intent that national water quality goals be pursued. The scarcely two-year old Environmental Protection Agency built upon its predecessors' activities by taking up the challenge and implementing this far reaching legislation.

As a result of Section 208 of The Act, State and local water quality management agencies were designated to integrate water quality activities. As point source discharges were increasingly brought under control and funds for the construction and upgrading of municipal sewage treatment plants were granted, the awareness of nonpoint sources (including urban runoff) as potential contributors to water quality degradation was heightened. Uncertainties associated with the local nature and extent of urban runoff water quality problems, the effectiveness of possible management and control measures, and their affordability in terms of benefits to be derived mounted as water quality management plans were developed. The unknowns were so great and certain control cost estimates were so high that the Clean Water Act of 1977 (P.L. 95-217) deleted Federal funding for the treatment of separate stormwater discharges. The Congress stated that there was simply not enough known about urban runoff loads, impacts, and controls to warrant making major investments in physical control systems.

In 1978, EPA Headquarters reviewed the results of work on urban runoff by the technical community and the various 208 Areawide Agencies and determined that additional, consistent data were needed. The NURP program was implemented to build upon pertinent prior work and to provide practical information and insights to guide the planning process, including policy and program development and implementation. The NURP program included 28 projects, conducted separately at the local level, but centrally reviewed, coordinated, and guided. While these projects were separate and distinct, most share certain commonalities. All were involved with one or more of the following elements: characterizing pollutant types, loads, and effects on receiving water quality; determining the need for control; and evaluating various alternatives for the control of stormwater pollution. Their emphasis was on answering the basic questions underlying the NURP program and providing practical information needed for planning.

# CHAPTER 2
# BACKGROUND

## EARLY PERCEPTIONS

As noted earlier, drainage is perhaps the single most important factor of the urban hydrologic cycle. Nuisance flooding, more than anything else, gives Public Works directors concern, as complaints are received from unhappy motorists, residents, and business. Drainage has typically been considered a local responsibility, usually that of the City or County Public Works Department. Rarely does this responsibility go to the State or Federal level, except in cases of catastrophic flooding involving risk to human life and extensive property damage.

By 1964, the U.S. Public Health Service had begun to be concerned about identified pollutants in urban runoff and concluded that there may be significant water quality problems associated with stormwater runoff. In 1969, the Urban Water Resources Research Committee of the American Society of Civil Engineers (directed by M. B. McPherson and sponsored by the U.S. Geological Survey) recognized the potential threat of pollution from urban runoff and described a research program intended to obtain needed information to characterize urban stormwater quality.

In the late 1960's, the Federal Water Quality Administration (FWQA) conducted a study in an area of Tulsa, Oklahoma which was served by separate storm sewers. This first attempt at using regression analysis on urban runoff indicated that there was only a very poor correlation between stormwater runoff quantity and water quality constituents (except for suspended solids). Comparing the concentrations of various pollutants examined by this study (separate storm sewers) with previous data on combined sewer overflows indicated that storm runoff from areas having separate sewers had much lower values for BOD, fecal coliform, and most other pollutant concentrations. The study concluded that the largest portion of pollutants resulted from (1) washoff of material from impervious surfaces and (2) the erosion of drainage channels (caused by high volumes of runoff from the impervious surfaces). Control of urban runoff was recommended to reduce both runoff volume and rates.

Atlanta, Georgia is an example of a city that has both a combined sewer system and a separate system. In 1971, EPA conducted a study which compared the contribution of various sources of pollutants. It was concluded that, on an annual basis, 64 percent of the BOD load came from separate storm sewers, and 19 percent came from combined sewers, the balance coming from treatment plants.

In 1971, EPA also conducted a study in Oakland and Berkeley, California, to assess the infiltration of stormwater into sanitary sewers. While only four percent of the study area had combined sewerage and the remaining 96 percent separate, the study made it clear that infiltration can cause a separate system to function as though it were combined.

Studies in Sacramento, California, which has both combined and separate storm sewers, indicated that the stormwater was comparable to the average strength of domestic wastewater. However, the concentrations for BOD were found to be so unrealistically high, that contamination of the runoff by raw sanitary sewage was considered to be a distinct possibility.

In 1973, the Council on Environmental Quality published a report titled, "Total Urban Pollutant Loads: Sources and Abatement Strategies." The primary conclusion was that much pollution was coming from urban runoff and that, unless it was taken care of, the goals of the Act would not be met.

CONCLUSIONS FROM SECTION 208 EFFORTS

EPA guidance for conducting the early 208 planning efforts designated 17 topic areas (including urban runoff) that were to be addressed by all Water Quality Management agencies in developing their 208-funded plans. Although all topic areas were to be covered, the degree of emphasis to place on each was left to the individual agencies to decide. As a result, the amount of the 208 efforts spent in the area of urban runoff varied greatly (but was rarely a major portion).

Many of the 208 agencies began their studies with the assumption that urban runoff was an important cause of water quality problems. Although the studies developed much information on runoff and receiving waters, not enough basic information was known to assess urban runoff's role as a major cause of problems. This was partly because of interferences by other sources and complex relationships within the receiving waters. It was also due to the difficulties in deciding what constitutes a "problem." In some cases, "problems" were synonymous with criteria violations; in others, "problems" were synonymous with an impairment or denial of beneficial uses. In many cases, "problems" were concluded to exist, simply on the basis of the possible presence of certain contaminants in urban runoff, based solely on values taken from literature regarding studies conducted elsewhere. The practical implication of these differences (which were differences in viewpoints rather than differences in physical conditions, in many cases) was that local agencies were very reluctant to commit to implementing urban runoff controls in the absence of a clear problem definition.

Furthermore, in the early years of the 208 program, EPA's guidance on how to address urban runoff was vague. As a result, local agencies took a wait-and-see attitude on the stormwater portion of their plans. They simply did not know what EPA would eventually do on the issue of stormwater control.

Another major obstacle to implementation resulted from the uncertainties regarding the effectiveness of controls. Many of the measures proposed for controlling urban runoff are either new or special applications of conventional practices developed for other purposes. Little was known about how well they would work in urban runoff applications. Engineers, planners, public works personnel, and other decision makers have been understandably reluctant to invest large amounts of time and money in controls which may not perform as hoped.

Another obstacle to implementation of controls was a lack of basic data on sources, transport mechanisms, and receiving water characteristics (hydrologic and water quality aspects). Some of the more important topic areas where knowledge was lacking are summarized below:

- Sources - Not enough was known about where pollutants originate. Major sources certainly include vehicles, vegetation, erosion, fertilizer and pesticide application, litter, animals, and air pollution. However, a better understanding of source contributions could enhance control opportunities.

- Washoff/transport mechanisms - Not enough was known about how pollutants get from the sources to the receiving waters. Models could be better used for simulating runoff in problem definition and control evaluation, if they more accurately reflected washoff and transport mechanisms.

- Impacts - It was difficult to go beyond speculation in assigning urban runoff its proper share of responsibility for problems in cases where several pollutant sources contribute. In cases where other sources create obvious problems, it was difficult to determine the appropriate degree to which urban runoff should be controlled.

- Relative benefits - Planners had difficulty deciding whether the various benefits of controlling urban runoff quality justify the costs involved. There was considerable controversy over the present dry weather standards' relationship to beneficial uses, given the time and space scales of storm events and their intermittent nature. Many plans failed to be implemented because of uncertainties regarding: How much control is enough? Who benefits? Who should pay? Who should decide?

- Controls - Both cost and effectiveness data on full-scale control programs were lacking. Some of the control measures cited for typical 208 plans were plausible candidates, but their application for the purpose of urban runoff pollution control had not been studied quantitatively.

EPA'S ORD EFFORT

During the past 15 years, EPA's Office of Research and Development (ORD) has conducted over 250 studies on the characterization and control of stormwater discharges and combined sewer overflows, with particular emphasis on the latter due to their greater pollution potential. Consistent with overall Agency policies, ORD has deemphasized studies on receiving water impacts and effects (although it has done some such work). Rather, ORD has focussed principally on multi-purpose analyses and controls, because it is nearly impossible to segregate benefits and strategies of urban stormwater runoff pollution control from drainage, flood, and erosion control. Many significant results have been obtained by ORD's effort, which has dramatically increased the technical literature in the area.

Data from ORD studies indicate the high variability of pollutant concentrations in urban runoff. Based on loading projections, it is safe to conclude that urban stormwater can contribute significant pollutant loads to receiving waters, in many cases having pollutant concentrations on the order of secondary treatment plant effluent for some constituents. Nonetheless, in its efforts to find direct urban runoff generated receiving water impacts (using the conventional dissolved oxygen parameter as the indicator) ORD has been only partly successful. However, this was only one study and was not intended to be the final word. Nonetheless, based on the size of the load coming from urban runoff, a significant pollution potential is there for at least some types of receiving waters. For example, a small urban lake could receive nutrient loads sufficient to increase algal productivity and accelerate the eutrophication process. The existence of heavy metals and certain organics (mostly of petroleum origin) in urban runoff have also been documented by the ORD program.

In addition to studying urban runoff loads, the ORD program has investigated a number of management and control approaches. This effort has been very successful, and many innovative techniques have been proposed and tested. The results of such research, development, and demonstrations have been presented in reports which document many of these potential controls, thereby allowing the technology to be utilized in other programs and at other locations. Included have been such control measures as on-site (upstream) storage; porous pavement; the swirl concentrator, helical bend, tube settler, and fine mesh screens for grit and settleable solids removal; street sweeping; disinfection; and high rate filtration, dissolved air flotation, and microscreening for suspended solids and BOD removal. Most of these controls were developed principally to deal with combined sewer overflow problems. However, some may also have application in urban runoff control, once their effectiveness has been conclusively demonstrated and initial and operating cost data are available to allow the necessary trade-off studies to be made.

The ORD program's reports constitute an invaluable source of data and information that was used to design and guide the development of the emerging NURP program. Also, three of the NURP projects were joint efforts with ORD (i.e., West Roxbury, Massachusetts, Bellevue, Washington, and Lansing, Michigan).

## OTHER PRIOR/ONGOING EFFORTS

The Clean Water Act requires EPA to provide Congress with a needs assessment every two years in the six categories of the construction grant funds program. In 1974, the Needs Survey for Separate Storm Sewer Discharges (Category VI) was done by each state. Using the goals of the Act as the criteria to be met, they identified a cost of about $235 billion (June 1973 dollars). One state alone identified $80 billion in needs to control separate storm sewer discharges. In 1976, the Needs Survey was conducted by the Agency, and it was found that Category VI would require $66 billion to meet the goals of the Act. This survey broke the goals into three categories or levels of pollution abatement; (1) aesthetics, (2) fish and wildlife, and (3) recreation. Costs to meet each category were determined.

As noted previously, the ASCE defined a program in 1969 to identify the causes and effects of urban stormwater pollution. The recommendations were not followed, so in 1974 at the Rindge, New Hampshire, Engineering Foundation Conference (jointly sponsored with ASCE's Urban Water Resources Research Council), a similar program was again recommended. A similar scenario occurred at the Easton, Maryland, conference of 1976 sponsored by the same group.

DISCUSSION

In the past (ca 1890), dilution was considered to be the appropriate way to control combined sewer overflows, since the primary concern was odor and related nuisances. Between 1890 and 1960 little concern was shown for stormwater pollution. Stormwater concerns were primarily related to drainage problems. As time progressed, water quality began to be considered, and workers began to characterize problems in terms of concentrations of certain pollutants and loads of these pollutants. In the 1970's, problems were being defined in terms of pounds of pollutants needing to be removed from overflows, in the interest of preventing pollution.

Past work, reported by EPA and published in professional journals, tended to focus on determining (a) the type and amount of pollutants involved and/or (b) methods to reduce the loads. However, such reports and articles did not consider either the level of improvement attainable or the need to improve quality of the receiving water body associated with the study. A conclusion common to all such reports was that not enough was known about stormwater to adequately understand cause and effect relationships. Also common to such reports were recommendations for further study and more data. A tangible result of the lack of belief and uncertain attitude in this area is the fact that stormwater controls for water quality have been implemented in so few places throughout the nation. Thus, there has been a critical need to objectively examine the situation.

Many factors led to the development of NURP, one being a legally-mandated necessity. As implementation of P.L. 92-500 moved into full swing, the lack of progress in the area of urban runoff was becoming apparent. In 1974 EPA lost a court case, which led to the decision that EPA should issue permits for separate storm sewer discharges. In 1976 EPA requested that the Areawide Waste Management Planning Program focus on the three or four most important of the 17 items required by the regulations. Many of the 208 Areawide Agencies cited urban runoff as an important item.

Two years later, EPA reviewed ninety-three 208 Areawide Agencies' work plans to assess their basis for having identified urban runoff as an element upon which they would focus. Review of these projects' methods and findings did not provide much to further our understanding of the pollution aspects of urban runoff. If one reason can be identified, it was the lack of site-specific data to define the local conditions.

As mentioned earlier, the Rindge Conference recommended a candidate program for obtaining the data necessary to provide a good understanding of stormwater pollution (EFC/ASCE, 1974). It is not coincidental that the NURP program is quite similar in design to those recommendations.

## THE NATIONWIDE URBAN RUNOFF PROGRAM

### Program Design

NURP was not intended to be a research program, per se, and was not designed as such. Rather, the program was intended to be a support function which would provide information and methodologies for water quality planning efforts. Therefore, wherever possible, the projects selected were ones where the work undertaken would complete the urban runoff elements of formal water quality management plans and the results were likely to be incorporated in future plan updates and lead to implementation of management recommendations. Conduct of the program provided direction and assistance to 28 separate and distinct planning projects, whose locations are shown in Figure 2-1 and listed in Table 2-1, but the results will be of value to many other planning efforts. NURP also acted as a clearinghouse and, in that capacity, provided a common communication link to and among the 28 projects.

The NURP effort began with a careful review of what was known about urban runoff mechanisms, problems, and controls, and then built upon this base. The twin objectives of the program were to provide credible information on which Federal, State, and local decision makers could base future urban runoff management decisions and to support both planning and implementation efforts at the 28 project locations.

An early step in implementing the NURP program involved identifying a limited number of locations where intensive data gathering and study could be done. Candidate locations were assessed relative to three basic selection criteria:

- Meeting program objectives;
- Developing implementation plans for those areas; and
- Demonstrating transferability, so that solutions and knowledge gained in the study area could be applied in other areas, without need for intensive, duplicative data gathering efforts.

The program design used for NURP included providing a full range of technical and management assistance to each project as the needs arose. Several forums for the communication of experience and sharing of data were provided through semi-annual meetings involving participants from all projects. The roles and responsibilities of the various State, local, and regional agencies and participating Federal agencies were clearly defined and communicated at the outset. These were reviewed and revised where warranted as the projects progressed.

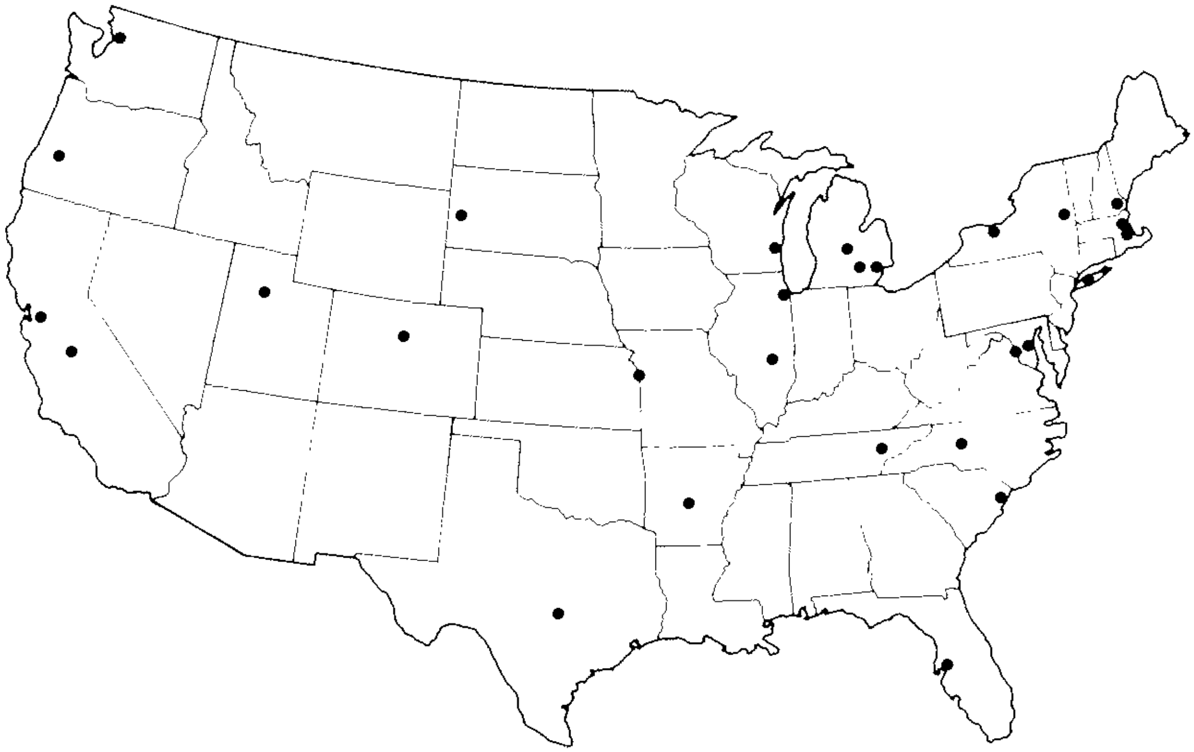

Figure 2-1. Locations of the 28 NURP Projects

TABLE 2-1. NURP PROJECT LOCATIONS

| EPA Region | NURP Code | Project Name/Location | EPA Region | NURP Code | Project Name/Location |
|---|---|---|---|---|---|
| I | MA1 | Lake Quinsigamond (Boston Area) | V | IL1 | Champaign-Urbana, Illinois |
| | MA2 | Upper Mystic (Boston Area) | | IL2 | Lake Ellyn (Chicago Area) |
| | NH1 | Durham, New Hampshire | | MI1 | Lansing, Michigan |
| II | NY1 | Long Island (Nassau and Suffolk Counties) | | MI2 | SEMCOG (Detroit Area) |
| | NY2 | Lake George | | MI3 | Ann Arbor, Michigan |
| | NY3 | Irondequoit Bay (Rochester Area) | | WI1 | Milwaukee, Wisconsin |
| III | DC1 | WASHCOG (Washington, D.C. Metropolitan Area) | VI | AR1 | Little Rock, Arkansas |
| | MD1 | Baltimore, Maryland | | TX1 | Austin, Texas |
| IV | FL1 | Tampa, Florida | VII | KS1 | Kansas City |
| | NC1 | Winston-Salem, North Carolina | VIII | CO1 | Denver, Colorado |
| | SC1 | Myrtle Beach, South Carolina | | SD1 | Rapid City, South Dakota |
| | TN1 | Knoxville, Tennessee | | UT1 | Salt Lake City, Utah |
| | | | IX | CA1 | Coyote Creek (San Francisco Area) |
| | | | | CA2 | Fresno, California |
| | | | X | OR1 | Springfield-Eugene, Oregon |
| | | | | WA1 | Bellevue (Seattle Area) |

The 28 NURP projects were managed by designated State, county, city, or regional governmental associations. The U.S. Geological Survey (USGS) was involved with EPA as a cooperator, through an inter-agency agreement, on 1[illegible] of the NURP projects. The Tennessee Valley Authority was also involved in one project.

A major objective of the program was the acquisition of data. Because these data will be used for several years to characterize problems, evaluate receiving water impacts from urban runoff, and evaluate management practices, consistent methods of data collection had to be developed and rigorously employed.

Project Selection

Projects were selected from among the 93 Areawide Agencies that had identified urban runoff as one of their significant problems. The intention was to build upon what these agencies had already accomplished in their earlier programs. Also, projects that would be a part of this program were screened to be sure that they represented a broad range of certain characteristics (e.g., hydrologic regimes, land uses, populations, drainage system types). Actual selection of projects was a joint effort among the States, local governments, and Regional EPA offices. The five major criteria used to screen candidate projects were as follows:

1. Problem Identified. Had a problem relative to urban runoff actually been identified? Could that problem be directly related to separate storm sewer discharges? What pollutant or pollutants were thought to be causing the problem? Using the NURP problem identification categories, what was the "problem" (i.e., denying a beneficial use, violating a State water quality standard, or public concern)?

2. Type of Receiving Water. The effects of stormwater runoff on receiving water quality were the NURP program's ultimate concern. Because flowing streams, tidal rivers, estuaries, oceans, impoundments, and lakes all have different hydrologic and water quality responses, the types of receiving waters associated with each candidate project had to be examined to ensure that an appropriately representative mix was included in the overall NURP program.

3. Hydrologic Characteristics. The pattern of rainfall in the study area is perhaps the single most important factor in studying urban runoff phenomena, because it provides the means of conveyance of pollutants from their source to the receiving water. For this reason, projects in locations having in different hydrologic regimes were chosen for the program.

4. Urban Characteristics. Characteristics such as population density, age of community, and land use were considered as

possible indicators of the waste loads and ultimately the rainfall-runoff water quality relationship. The type of sewerage system was another factor considered (e.g., whether it is combined, separate, or mixed; how severe the infiltration and inflow problems may be). Such factors have different effects on the quantity and quality of storm runoff, and were balanced as well as possible in selecting projects.

5. Beneficial Use of Receiving Water. Because this factor greatly affects the type of control measure that would be appropriate, attempts were made to include a wide range in selecting projects.

Although these were the primary criteria used to identify potential projects, other factors also had to be considered (e.g., the applicant agencies' willingness to participate, the State's acceptance of the project, the experience of the proposed project teams). Because the NURP program used planning grants (not research funds) a major consideration was the anticipated working relationships with local public agencies and the applicants' ability to raise local matching funds.

Program Assistance

Technical expertise and resources available for urban runoff planning varied among the various projects participating in NURP. Therefore, the program strategy called for providing a broad spectrum of technical assistance to each project as needed and for intercommunication of experiences and sharing of data in a timely manner.

Assistance was also provided to the applicants in developing their final work plans. This was done to ensure that there would be consistency among methods, especially in the collection of data. If there were to be differences in data from city to city, they must be due to the characteristics of each city and not a result of how the data were obtained.

Assistance with instrumentation was provided during the program in the form of information on available equipment, installation, calibration, etc. Because one of the more important elements of a data collection program is the "goodness" or quality of the data themselves, questionable data would be of little use. Accordingly, a quality assurance and quality control element was required in the plans for each project.

Periodic visits were made to each project site to ensure that the participants were provided opportunities to discuss any problems, technical or administrative. The visiting team typically included an EPA Regional Office representative, an EPA Headquarters representative, and one or two experienced consultants. All interested parties, including representatives from State or local governments, were requested to attend those visits.

As the projects moved farther into their planned activities and the time for data analysis approached, each project was required to describe how they were going to analyze their data. No single method was recommended for each project, because it was believed that a broad diversity of available methods would be suitable, if used properly. Guidance on proper use was provided as a part of technical assistance through project visits and special workshops for this purpose.

Communication

It was intended that the entire group of NURP participants function as a single team. Accordingly, a communication program was developed. National meetings were conducted semi-annually so that key personnel from the individual projects would have an opportunity to discuss their experiences and findings.

Reports were required of each project quarterly. EPA Headquarters also provided composite quarterly reports summarizing the status of each project and discussing problems encountered and solutions found.

# CHAPTER 3
# URBAN RUNOFF PERSPECTIVES

In evaluating the impacts of urban runoff, one's perspective may be influenced by one's concerns and priorities - and what one defines to be a "problem". Recognizing this, the following discussion covers several such perspectives, including concerns over runoff quantity, water quality, and control possibilities.

## RUNOFF QUANTITY

The following discussion covers a major cause and two major effects of runoff problems related to "quantity" (i.e., increased urbanization as a cause; flooding and erosion/sedimentation as effects).

### Flooding Problems

As noted earlier, drainage has historically been the principal local-level concern regarding urban runoff. Concerns over quantity can be divided into two basic categories: nuisance flooding and major flooding. Nuisance flooding (e.g., temporary ponding of water on streets, road closings, minor basement flooding), although hardly tolerable to those immediately affected, rarely affects an entire urban populance. Nonetheless, the concerns of the (often vocal) minority of affected citizens commonly reach the point where local action is taken to minimize the recurrence of such events. Such mitigation activities are usually locally determined, funded, and implemented because both the affected public and government decision makers perceive and concur that such flooding constitutes a "problem".

Catastrophic flood events, on the other hand, have to be thought about differently for several reasons:

- They typically affect the majority of the urban populace.

- Mitigation measures often involve engineering improvements extending well beyond local jurisdictions.

- Mitigation measures often cost more than the local community could afford. Historically, the Federal government has become involved, in major flood control efforts through a number of related programs. In such cases, water quantity problems are relatively easy to define because the extent of flooding is readily observable, the degree of damage is easily determined, and the benefits of proposed flood control projects can be estimated. Thus, decision makers face a relatively low risk in prescribing courses of action and justifying the associated costs in light of benefits. As will be discussed later, decision making in the case of water quality concerns is less straightforward.

## Erosion and Sedimentation Problems

Erosion results from rainfall and runoff when soil and other particles are removed from the land surface and transported into conveyance systems and water bodies. Since land surface erosion is the principle source of stream sediment, the type of soil, land cover, and hydrologic conditions are major factors in determining the severity and extent of sedimentation problems. Although erosion is a natural process, it is frequently exacerbated by the activities of man, in both urban and rural environments.

When addressing the broad spectrum of receiving water problems which result from sedimentation, it is convenient to divide cases into two categories; (1) those that respond to control measures directed at nuisance flood prevention, and (2) those that are not controlled by such measures. When natural loads are discharged into receiving waters, the effects are primarily physical and only secondarily chemical (because the mineral constituents which make up the primary sediment load are relatively benign in most cases). Among the physical problems imposed upon the receiving waters are:

- Excess turbidity reduces light penetration, thereby interfering with sight feeding and photosynthesis;

- Particulate matter clogs gills and filter systems in aquatic organisms, resulting, for example, in retarded growth, systemic disfunction, or asphyxiation in extreme cases; and

- Benthal deposition can bury bottom dwelling organisms, reduce habitat for juveniles, and interfere with egg deposition and hatching.

Although sedimentation is storm-event related, its resultant problems are not exclusively either "quantity" problems or water "quality" problems. Being hybrid problems, sedimentation control has received a mixed approach. The organizations involved range widely, from Federal agencies (e.g., the Army Corps of Engineers, the Soil Conservation Service) to local drainage and sedimentation control officials, frequently with involvement from State and county governmental agencies.

## Urbanization as a Cause of Problems

Urbanization accelerates erosion through alteration of the land surface. Disturbing the land cover, altering natural drainage patterns, and increasing impervious area all increase the quantity and rate of runoff, thereby increasing both erosion and flooding potential. Also, the sedimentation products which result from urban activities are generally not as benign as the natural mineral sediments which result from soil erosion. Atmospheric deposition (associated with industrial, energy, and agricultural production activities) and added surface particulates (resulting from tire wear, auto exhaust, and road surface decomposition) fall in this latter category. Their effects on receiving waters tend to be more "chemical" than "physical". They may contain toxic substances and/or other compounds which can have adverse impacts upon receiving water quality and the associated ecological communities.

## WATER QUALITY CONCERNS

The notion that urban runoff can be a significant contributor to the impairment or degradation of the quality of receiving waters has formed only recently and is not universally shared. It is the totality of receiving water characteristics (e.g., flow rate, size or volume, and physical and chemical characteristics) that determines its use, although some characteristics are more important than others (e.g., there must be present an appropriate rate of flow and/or volume in the receiving water to support the desired use).

In addressing the water quality needed to support a designated use, one must consider specific requisite characteristics. For example, in the case of swimming, total dissolved solids and dissolved oxygen levels are far less important than pathogenic organisms. For irrigation, the biochemical oxygen demand of the water is of little concern to the farmer, whereas the total dissolved solids level is of immense concern (to minimize salt buildup). Although high nutrient levels may be detrimental to the quality of impounded waters (by hastening eutrophication processes), a farmer may welcome nutrients in irrigation water.

It is also important to note that it is the concentration, rather than the mere presence of a water quality constituent, that affects use. The relationship between pollutant concentration and resultant impacts on receiving water use are quite non-linear, with plateau effects not uncommon. For example, consider dissolved oxygen and its effect upon fin fish. Down to a certain level below saturation, there are virtually no important effects (upon a given species). As dissolved oxygen levels fall below this threshold, the more sensitive members of the species begin to be affected. As levels continue to fall, the affected percentage of the population will increase until a level is reached at which the entire population can no longer survive. Obviously, any further reduction of dissolved oxygen level would have no further effect upon the community, since it no longer exists. It is important to keep this plateau effect in mind when considering the practical impacts of increased pollution and the practical value of remedial measures to restore beneficial uses, since limited removal of a polluting substance may do nothing to alleviate the problem. In the example given above, if one were to somehow reduce the input of oxygen demanding substances to the receiving water, the result might be that the dissolved oxygen level of the receiving water would rise from 1.0 mg/l to 3 mg/l. If the species of concern were trout, they still could not survive. Even though polluting substances were removed and money was spent, the desired benefit would not be achieved.

## WATER QUANTITY AND QUALITY CONTROL

There is no question that excessive urban runoff causes problems. Remedial costs may be high, but the benefits are obvious. Currently, there is a growing national awareness that, if steps are taken during the planning phase of development, excessive stormwater discharges can be prevented, at least from typical events (large infrequent storms will always present a greater threat).

## Past And Current Work

During the past two decades attention has been focused on reducing runoff rates and volumes and reducing flood damage. During the early 1970's, a manual of practices was prepared under grants from the Office of Water Research and Technology sponsored by the American Public Works Association stressing detention (Poertner, 1974). The University of Delaware also issued a manual of practices on methods to control rates and volumes of urban runoff (Toubier and Westmacott, 1974).

Work done by the ASCE Urban Water Resources Research Council during the sixties stressed the concept of natural easements for drainage, observing that there were two drainage ways; major routes for large events and minor routes for smaller more frequent events (Jones, 1968). It was claimed that money could be saved by using natural channels, swales, etc., thus reducing the need for more expensive concrete conveyances.

The idea of intentionally using natural runoff courses, green belts, and the like was new to engineers who had long been trying to control runoff through more artificial conveyances. In 1970, EPA's Office of Research and Development initiated work on a development known as the Woodlands project in Texas near Houston. Studies were conducted to determine how storm flows could be managed and water quality could be protected or improved by the use of natural drainage ways, detention facilities, porous pavements, increased infiltration rates, and a decrease in runoff rates (Characklis, 1979).

## Federal Involvement

As part of its national effort to control erosion from agricultural lands, the Soil Conservation Service (SCS) (Department of Agriculture) provides technical assistance in developing erosion control plans. During the past decade or so, the methods they have developed have been applied much more widely than just to agricultural situations. SCS has become increasingly involved in erosion control in urban areas and has produced a useful document for assessing urban hydrology in small watersheds (SCS, 1975).

Other Federal agencies that have an interest in urban runoff and its control include the U.S. Geological Survey, the Federal Highway Administration, the ~~Federal Housing Administration, the Tennessee Valley Authority, and others~~ too numerous to mention.

## State And Local Involvement

Although some 27 states have adopted floodplain management legislation to protect property, the control of urban drainage has traditionally been a local matter. Some states have some form of erosion control laws in force; however few states have runoff rate/quantity legislation. This situation has begun to change over the last decade, and Maryland is one example where the statewide legislation for stormwater management is implemented at the county level.

The methods used tend to be preventive, wherein erosion is controlled by prescribing certain proven design practices and conventions. Many local agencies are developing control plans along these lines, so this report will not cover this aspect of control.

PROBLEM DEFINITION

As pointed out earlier, water quantity problems are relatively easy to identify and describe. Water quality problems, on the other hand, tend to be more elusive because their definition often involves some subjective considerations, including experiential aspects and expectations of the populace. They are not immediately obvious and are usually less dramatic than, for example, floods. They also tend to vary markedly with locality and geographic regions within the country. For example, a northwestern resident may want to upgrade stream quality to support some highly-prized species of game fish, while a northeastern resident contemplating the river flowing by the local factory might be grateful to see any game fish at all. Thus, a methodological approach to the determination of water quality problems is essential if one is to consider the relative role of urban runoff as a contributor. An important finding of the work conducted during this NURP program has been to learn to avoid the following simplistic logic train: (a) water quality problems are caused by pollutants, (b) there are pollutants in urban runoff, therefore, (c) urban runoff causes "problems". The unspoken implication is that a "problem" by definition requires action, and any type of "problem" warrants equally vigorous action. It becomes clear that a more fundamental and more precise definition of a water quality "problem" from urban runoff is necessary. For this purpose, the NURP has adopted the following three-level definition:

- Impairment or denial of beneficial uses;
- Water quality criterion violation; and
- Local public perception.

The first of these levels refers to cases of impairment or denial of a designated use. An example would be a case where a determination has been made that some specific beneficial use should be attained; however, present water quality characteristics are such that attainment of the use cannot be fully realized.

The second level of problem definition refers to violations of a designated water quality criterion. An example would be a case where some measure or measures of water quality characteristics have been found to violate recommended or mandatory levels for the receiving water classification. Some of the subtle distinctions between this and the preceding problem definition arise in the fact that receiving water classification may not be appropriate, the beneficial use may not be impaired or denied, and the water quality criteria associated with that classification may or may not be overly conservative or directly related to the desired use.

The third level of problem definition involves public perception. This may be expressed in a number of ways, such as telephone calls to public officials complaining about receiving water color, odor, or general aesthetic appearance. Public perception of receiving water body problems is highly variable also. Some people enjoy fishing for carp or gar, children will play in almost any creek, and so on. This level of problem definition can also include one concept of anti-degradation. Here the thought is that no polluting substances of any kind in any quantity should be discharged into the receiving water regardless of its natural assimilative capacity. This concern has its ultimate expression in the "zero discharge" concept. EPA's concept of anti-degradation, on the other hand, refers to degradation of use; a subtle but essential difference.

The foregoing levels of problem definition provide an essential framework within which to discuss water quality problems associated with urban runoff. However, it is important to understand that when one is dealing at a local level all three elements are typically present. Thus, it is up to the local decision makers, influenced by other levels of support and concern, to carefully weigh each, prior to making a final decision about the existence and extent of a problem and how it is to be defined. It follows that, if this step of problem definition is done carelessly, it will be difficult, if not impossible, to plan an effective control strategy and establish a means for assessing its effectiveness.

# CHAPTER 4
# STORMWATER MANAGEMENT

## INTRODUCTION

This chapter is included for those who wish to know more about how to plan and implement stormwater management programs. Most of the information contained herein was developed through several related programs that were proceeding in parallel with the NURP program.

- The Southeast Michigan Council of Governments (SEMCOG), a NURP grantee, was developing stormwater management procedures.

- The Midwest Research Institute (MRI) was collecting cost information on control practices from selected NURP projects.

- A related EPA Water Planning Division program, the Financial Management Assistance Program (FMAP), was developing financial and institutional planning procedures designed to be helpful in the implementation of stormwater management plans.

## STORMWATER MANAGEMENT PLANNING[1]

Stormwater management planning develops policies, regulations, and programs for the control of runoff from the land. Stormwater management planning is normally directed toward either or both of two primary goals: the reduction of local flooding and/or the protection of water quality. However, stormwater management planning is also generally used to insure that stormwater programs and regulations provide multiple benefits to the affected communities and do so in a way that does not create additional problems.

Stormwater management planning need not involve expensive technical studies. Available data and maps, the experience of other communities, and advice from experts can be used to develop an effective planning program. Detailed technical studies can then be targeted toward specific issues and problems. Effective local planning can alleviate the need for costly remedial public works projects.

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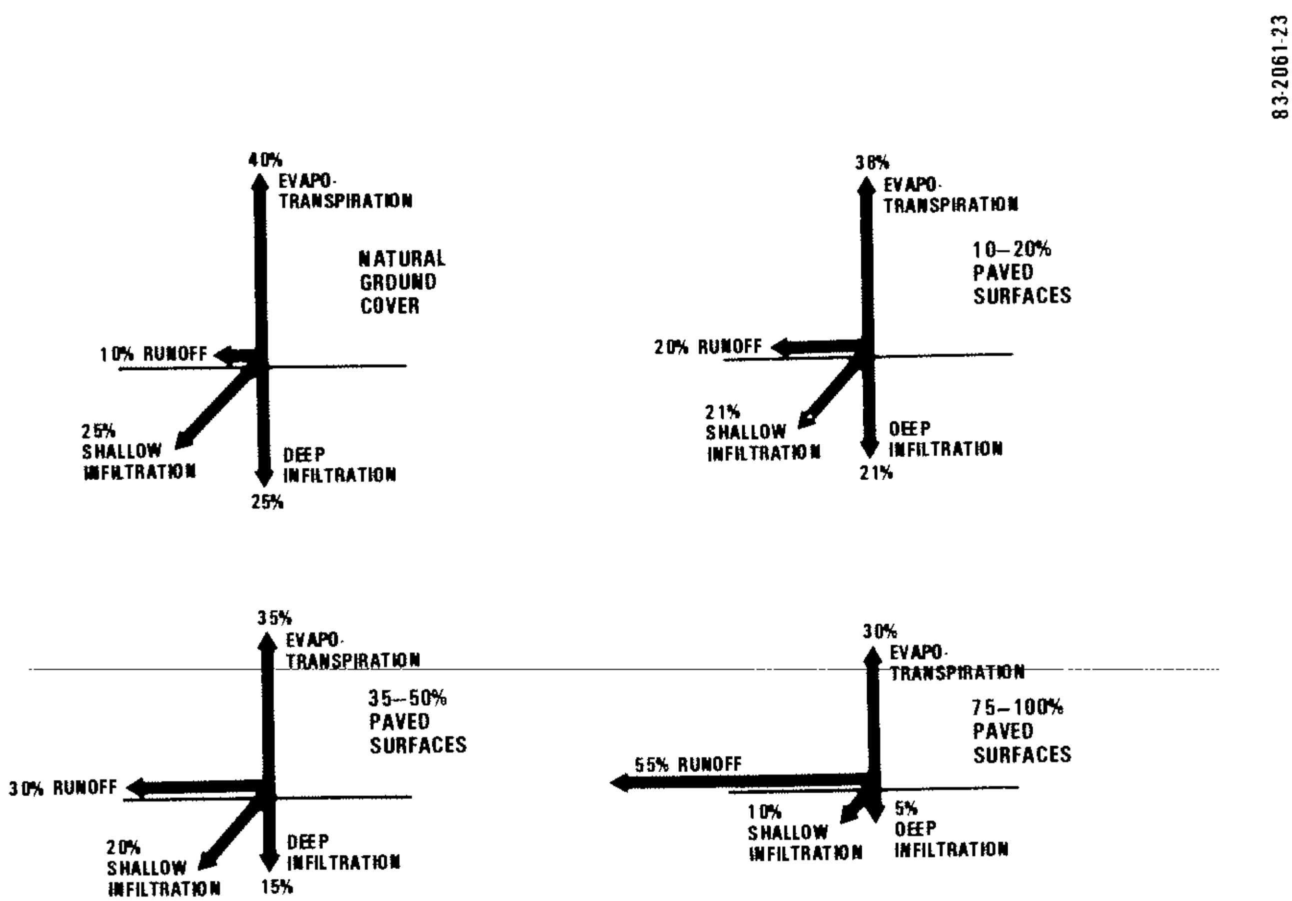
[1] The material in this section of the chapter is largely from Technical Bulletin No. 1: <u>Stormwater Management Planning: Cost-Saving Methods for Program Development</u>, the first of a seven-part bulletin series on water quality management prepared by the Southeast Michigan Council of Governments and available from Information Service, SEMCOG, 8th Floor, Book Building, Detroit, Michigan 48226.

## The Need

Stormwater runoff cannot be ignored in developing communities. As urban development occurs, the volume of stormwater and its rate of discharge increase. These increases are caused when pavement and structures cover soils and destroy vegetation which otherwise would slow and absorb runoff. Pollutants, washed from the land surface and carried by runoff into lakes and streams, may add to existing water quality problems.

Figure 4-1 illustrates the effects of paved surfaces on stormwater runoff volumes. When natural ground cover is present over the entire site, normally less than 10 percent of the stormwater runs off the land into nearby creeks, rivers, and lakes. When paved surfaces cover 10 to 30 percent of the site area, approximately 20 percent of the stormwater can be expected to run off. As paved surfaces increase, both the volume and the rate of runoff increase. Furthermore, paved surfaces prevent natural infiltration of stormwater into the ground, and increased runoff volumes and rates increase soil erosion and pollutant runoff. Stormwater management planning can be used to develop programs to reduce adverse affects and even to provide community benefits.




Source: J.T. Tourbier and R. Westmacott, ***Water Resources Protection Technology: A Handbook of Measures to Protect Water Resources in Land Development,*** p. 3.

Figure 4-1. Typical Changes in Runoff Flows Resulting from Paved Surfaces

Stormwater management can and should be directed toward two goals: the control of runoff flows (i.e., volumes and rates) and the control of pollutants in stormwater. Control measures which emphasize the storage of runoff rather than the immediate conveyance from the site and from the community often provide benefits which meet both goals. Stormwater storage and conveyance measures, however, affect the community in a variety of ways. Through stormwater management planning the effects of alternative policies, programs, control measures, and financing schemes can be evaluated.

Stormwater management planning is directed toward basic policy questions, such as:

- What should be done with runoff from the land?

- Is the temporary (detention) or permanent (retention) storage of stormwater runoff desirable?

- Under the circumstances, should retention basins, detention basins, natural infiltration areas, or dished parking lots be used to store runoff?

- What requirements should be placed on new developments?

- Do stormwater runoff problems in developed areas warrant special attention?

- Should communal retention or detention facilities be provided by the local jurisdiction? If so, how can such areas be financed?

- Who should pay for retention and detention facilities on private property?

- Are the local jurisdictions already carrying out programs (such as parkland acquisition programs or wetlands regulation) which affect stormwater runoff? Can programs and/or regulations be coordinated to achieve multiple purposes?

- Should enclosed drains or natural channels be used to convey stormwater to and from storage areas?

- Can routing and storage be provided for major storms (e.g., 100-year frequency) as well as minor storms (e.g., 10-year frequency)?

- Who should be responsible for facility maintenance?

The specific questions to be addressed in a local government planning program will vary among local jurisdictions, reflecting varying problems and community objectives. The answers to these questions may take the form of policy statements, changes in regulations or engineering design standards, technical assistance materials for landowners or consulting engineers, revisions to existing programs, or a written plan document.

Because stormwater management planning for quantity and quality control is relatively new, and because community stormwater concerns differ, there are no easy formulas for preparing stormwater management plans.

Stormwater Runoff as a Community Resource

Although, stormwater management programs are typically undertaken to avoid problems (e.g., flooding, pollution, lawsuits), effective planning can also be used to pursue potential community benefits. When effectively managed, stormwater can provide benefits such as:

- Recharge of groundwater supplies;
- Water quality enhancement;
- Recreational opportunities (e.g., use of large retention areas for boating, fishing, or nature study);
- Replenishment of wetlands which serve as wildlife habitats, absorb peak floods, and naturally break down certain pollutants;
- Maintenance of summertime lake levels and stream flows; and
- Enhancement of community appearance and image when facilities are attractively designed.

The Role of Local Governments

In some cases, the institutional systems for stormwater management may need to be complex, largely because State, county, and local agencies' policies, regulations, and procedures may all affect stormwater control within a particular development. For example, in Michigan, the following roles apply:

- County drain commissioners construct and manage county drains and also review subdivision plans to assure adequate drainage.
- County highway departments affect drainage in new developments by regulating connections to roadside drains and ditches.
- The State Department of Natural Resources regulates wetlands, dam construction, and floodplain alterations.
- The State Water Resource Commission issues permits for certain stormwater discharges when known water quality problems can be linked with a particular activity, (e.g., certain storm drains, animal feeding operations, industrial parking lots).
- Both the State Department of Public Health and county drain commissioners regulate drainage in proposed mobile home parks.
- County agencies and certain local governments issue erosion and sediment control permits for certain development sites.

Furthermore, there has been increasing emphasis upon the consideration of environmental factors in land use decisions. Recent amendments to the City or Village Zoning Act and the Township Rural Zoning Act have clarified the legal authority of local governments to complete site plan reviews for environmental management purposes. Standards for the review of land uses must be included in local ordinances and take natural resource preservation into account. The Michigan Environmental Protection Act (MEPA) (Act 127, P.A. of 1970) places a duty on all government agencies to prevent or minimize water pollution and other environmental problems while carrying on regular activities. Section 5(2) of MEPA addresses the actions of local officials in the following terms:

> In any ... administrative, licensing or other proceedings, and in any judicial review thereof, any alleged pollution impairment or destruction of the air, water or other natural resources or the public trust therein, shall be determined, and no conduct shall be authorized or approved which does, or is likely to have such effect so long as there is a feasible and prudent alternative consistent with the reasonable requirements of the public health, safety and welfare.

Environmental aspects of stormwater runoff may be addressed by local officials in response to MEPA.

None of the above laws specifically require local governments to undertake stormwater management programs. Instead, local governments have a wide range of possible roles available to them. Stormwater management planning programs can be directed toward the review of existing State and county programs affecting stormwater runoff and toward the evaluation of alternative roles for the local government.

Possible roles for local governments in stormwater management include the following:

- <u>Planning</u> - The term "stormwater management planning" refers to the process of developing policies, programs, regulations, and other recommendations to chart the future course of the community in terms of stormwater management. Such planning can address existing problems or help to avoid future problems and community expenses.

- <u>Regulations</u> - Stormwater runoff control for each site plan and subdivision plan can be reviewed and approved by the local government.

- <u>Design and Construction</u> - Storm drainage facilities (e.g., pipes, basins, areas for retention) can be designed and constructed by the local government. Purchase of lands to serve as community stormwater retention areas may also be undertaken.

- <u>Inspection and Maintenance</u> - Requirements for regular inspection and maintenance of stormwater facilities, including drains and retention or detention basins, may be enforced by local governments. Requirements for easements are usually part of maintenance programs. Local governments may choose to undertake maintenance as a community service (such as a utility) or may require maintenance through contractual agreements with property owners.

The types of programs developed and the role assumed by a local government should, of course, reflect available financing options as well as program needs and management gaps.

FINANCIAL AND INSTITUTIONAL CONSIDERATIONS[2]

The traditional planning approach would ideally culminate in the successful implementation of a detailed design. In many cases, however, this objective is not accomplished due to financial and institutional constraints. Often a study team will fail to adequately consider such institutional and financial issues as who will manage the system and how will it be financed, thus creating a gap between technical planning and implementation. This omission is illustrated in Figure 4-2.

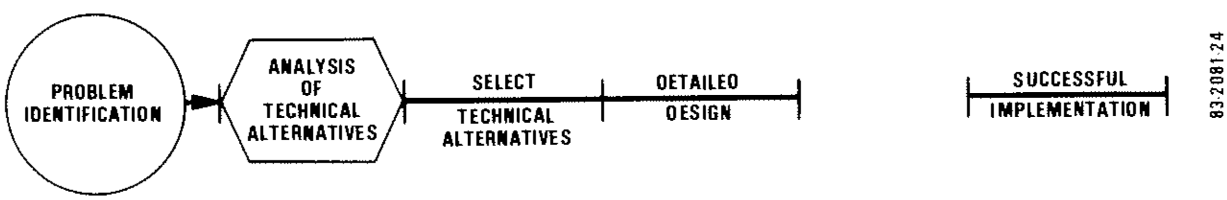



Figure 4-2. Incomplete Water Quality Planning

The implementation gap that results from the traditional planning approach has occurred all too often in attempts to control urban runoff.

As an illustration of the need to integrate financial and technical planning, consider the traditional process for developing a program to control construction runoff. A typical outcome of the process is a new ordinance. To reach this outcome, some of the issues that are normally considered from the technical perspective include:

- What are the technical construction requirements to be set out in the ordinance?

- What control measures will be required?

- How will compliance be monitored?

[2] This material is largely from the draft document, Planning for Urban Runoff Control: Financial and Institutional Issues, December 1981, prepared for FMAP by the Government Finance Research Center of the Municipal Finance Officers Association, Washington, D.C.

To balance the planning process, this technical analysis should be expanded to include financial and institutional issues such as:

- Does the city have legal authority to implement each requirement in an ordinance?
- How much will each cost, and who will pay for implementation of the control measures?
- Who will conduct compliance review, and who will pay for the reviews?

Numerous additional factors increase the need for financial and institutional analysis in all water quality management planning. Examples might include:

- Implementation of control programs occurs at the local level, and local budgets are being tightened as water quality expenditures compete with other local demands.
- Benefits from water quality projects are difficult to quantify and often accrue to people living downstream.
- It is becoming more difficult to obtain municipal funds through the bond market because of high interest rates.
- The cost of pollution controls is often sizable and difficult to allocate to specific polluters or beneficiaries.

These problems affect most areas of water quality management, but they are especially important in identifying and implementing solutions to urban runoff pollution.

Integrated Approach

An integrated planning approach helps water quality planners make the best control decisions in light of many complex issues. This approach takes the traditional planning process and adds to it financial and institutional elements at each step along the way. This integration is shown in Figure 4-3, with the traditional approach illustrated along the upper track and the financial and institutional elements added along the lower track.

During the early planning stages, financial and institutional issues are reviewed on a preliminary basis. This information becomes more detailed and refined as planning proceeds. Ultimately, the information forms the basis for a financial and institutional plan that supports the detailed design of a control alternative.

When very complex problems are being evaluated, it may be advisable to use a preliminary matrix early in the evaluation process for screening-out unacceptable alternatives. This approach permits a more detailed evaluation of issues surrounding the two or three best alternatives before a final selection is made. An example of a preliminary matrix is given in Figure 4-4.

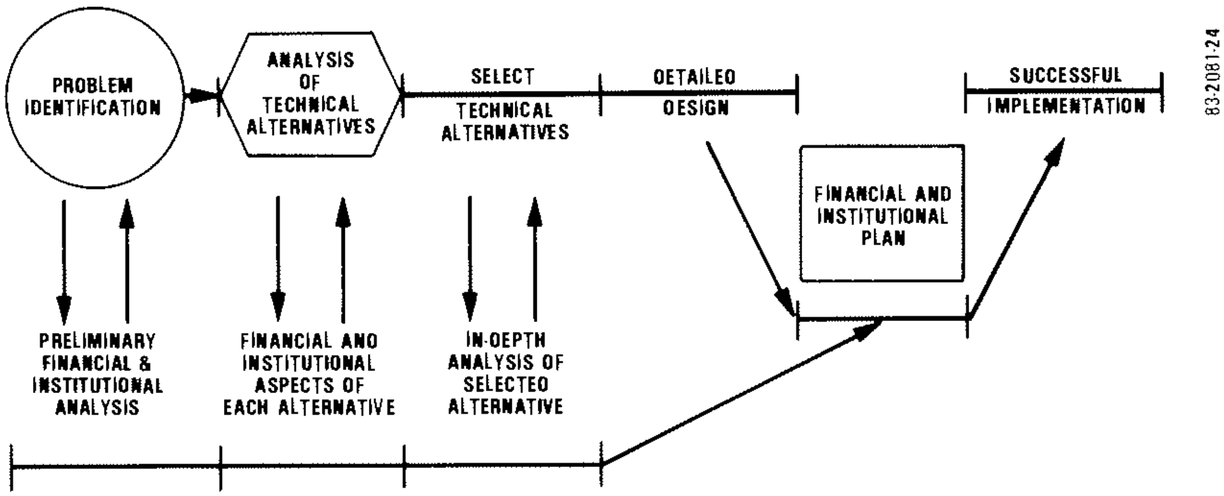



Figure 4-3. Integrated Water Quality Planning

| CONTROL APPROACH | TECHNICAL DESCRIPTION | EFFECTIVENESS IN CONTROLLING POLLUTION | FINANCIAL ISSUES: NET PRESENT VALUE | FINANCIAL ISSUES: ABILITY TO PAY | INSTITUTIONAL ISSUES |
|---|---|---|---|---|---|
| • SEPARATE SEWERS | CONSTRUCT NEW STORM SEWERS IN COMBINED AREAS | 100% EFFECTIVE IN ELIMINATING CSOs | $1 BILLION | EXCEEDS CITY'S BONDING CAPACITY | EXISTING INSTITUTIONS COULD HANDLE THE PROJECT |
| • SELECTIVE EXPANSION OF UNDERSIZED TRUNK SEWERS | REMOVE BOTTLENECKS, REDUCE NUMBER OF OVERFLOW EVENTS | 50% EFFECTIVE | $200 MILLION | IF STAGED OVER 10 YEARS, COULD BE FINANCED BUT WOULD RESTRICT OTHER PROGRAMS | EXISTING INSTITUTIONS COULD HANDLE THE PROJECT |
| • CONSTRUCTION OF DETENTION BASINS | CONSTRUCT 10 DETENTION BASINS SIZED TO HOLD THE FIRST FLUSH FROM A STORM | 30% EFFECTIVE | $50 MILLION | IF STAGED OVER 5 YEARS, COULD BE FINANCED; COULD RESTRICT OTHER PROGRAMS | NEW ORGANIZATION MIGHT BE NEEDED TO MAINTAIN AND AND OPERATE BASINS |

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Figure 4-4. Preliminary Matrix for Selection of a Control Approach (Combined Sewer Overflows)

Once a control approach is selected, a detailed design and a financial and institutional plan can be prepared. Figure 4-5 illustrates the major features of a financial and institutional plan. Key features of the detailed analysis required to prepare this plan are discussed in the following section.

**INSTITUTIONAL SECTION**

- RESPONSIBLE AGENCY
  - OPERATING PLAN
  - STAFFING NEEOS
  - ORGANIZATIONAL STRUCTURE
- LEGISLATIVE NEEOS
  - LEGAL ANALYSIS
  - ORAFT OROINANCES
  - ASSISTANCE NEEOEO

**FINANCIAL SECTION**

- PROGRAM COST
  - OPERATING BUOGET
  - CAPITAL REQUIREMENTS
- PROGRAM REVENUE
  - FUNOING SOURCES
  - FLOW OF FUNOS
  - PROGRAM CASH FLOW
  - COST ALLOCATION FORMULA
- OTHER FACTORS
  - FINANCIAL BUROEN ON PARTIES PAYING FOR THE PROGRAM
  - SENSITIVITY OF COST ANO REVENUE ESTIMATES TO CHANGES IN FINANCIAL ASSUMPTIONS
  - INOIRECT IMPACTS

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Figure 4-5. Major Components of a Financial and Institutional Plan

Key Financial and Institutional Elements

There are six essential elements[3] of financial and institutional analysis which provide a structure for the integrated planning process;

- institutional assessment,
- cost analysis,
- revenue analysis,
- ability-to-pay analysis,
- sensitivity analysis, and
- indirect impact analysis.

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[3] These elements were first defined in Planning for Clean Water Programs: The Role of Financial Analysis, U.S. EPA's Financial Management Assistance Program by the Government Finance Research Center of the Municipal Finance Officers Association, September 1981.

Each of these elements threads through the planning process and becomes more definitive as the process proceeds. The following discussion defines each element and identifies its major features.

## Institutional Assessment

The institutional assessment identifies the organizations or participating agencies that would be affected or involved in implementing a particular control program. The role of each entity in a program is evaluated with respect to its interest in solving the problem and its planning, management, operating, and regulatory capabilities. If the study team identifies an urban runoff problem, a preliminary institutional analysis can provide insight into capabilities of agencies that may be asked to play a role in the implementation and can, in some cases, aid in determining the types of technical alternatives that are analyzed.

The key factors to consider in evaluating an agency's capabilities are its statutory authority and organizational ability. In order to control urban runoff, an agency must have or be able to obtain the authority to implement a control measure. The authority of an agency can be assessed by thoroughly reviewing applicable federal, state, and local legislation. This review helps to determine which agency can best manage a given problem and highlights areas where additional legislation or local ordinances are needed.

## Cost Analysis[4]

A cost analysis is performed to identify the additional capital, operational, maintenance, and administrative costs of each activity that is part of a control program. These costs are estimated for each agency responsible for an activity. Cost estimates are prepared in uninflated dollars (using today's cost for all projections into the future) and brought back to their present value (or present worth) for comparison among alternatives. The interest rate to be used in the present value analysis is the agency's current interest rate for borrowing funds minus the expected rate of inflation.[5]

Cost analysis of control alternatives is included in increasing detail in each step of the planning process. It begins with "ball park" estimates in early stages which are refined as the process progresses and finalized in the detailed financial plan.

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4 A substantial part of this material is from a report, Collection of Economic Data from Nationwide Urban Runoff Program Projects, prepared for EPA by the Midwest Research Institute, 425 Volker Boulevard, Kansas City, MO 64110.

5 For a further discussion of present value analysis, see pp 36 to 42 of Facilities Planning 1981, U.S. Environmental Protection Agency, FRD-20, 1981.

Cost estimates cannot be static. They are prepared on a preliminary basis when an alternative is first considered and detail is added as an alternative becomes more feasible. As the planning process progresses, estimates are updated on a regular basis to account for changing costs.

To update and improve available data on the costs of specific urban runoff BMPs, EPA conducted a program to guide, assist, and coordinate the efforts of selected NURP projects in gathering cost data on the BMPs and BMP systems which they were evaluating as part of the NURP national workplan. A report[6] was prepared to summarize the preliminary economic data submitted by the NURP projects. Economic data were submitted for street sweeping, detention basins, catch basin cleaning, ocean discharge control systems, and a public education/information program by nine projects. The data must be considered preliminary and subject to change, particularly annual operating cost data. Most of the capital cost data are well documented and represent the actual cost of the BMP control and will not change. The annual operating cost data, however, range from detailed analyses to estimates, and some of the data reported are incomplete. Since most of the projects were still in progress, incomplete operating cost data were to be expected.

The capital costs of street sweepers varied from $21,988 (in 1975) to $40,000 in 1981. The annual operating costs of street sweeping programs varied from $53,445 to $1,138,097. The unit cost varied from $16.80 to $45.45 per hour of operation, and from $5.95 to $23.36 per curb-mile swept. This wide range indicates that many variables affect the actual cost of operating a street sweeper.

The installed capital costs of recharge basins in Fresno, California, ranged from $933,750 to $5,587,000. BMP modifications to three detention basins in Oakland County, Michigan, cost $2,345 to $8,442. The installed capital cost of the modifications to the wet pond in the Lansing, Michigan project was $50,149. Construction of the wet pond in the Salt Lake County, Utah project cost $41,138; modifications to the dry pond included placing aluminum plates in an existing underdrain and installing a redwood outlet skimmer at a nominal cost of $371.

The annual operating costs of the Fresno, California, basins range from $1,625 to $7,975. The annual cost for the basin in Lansing, Michigan is incomplete and includes only the interest cost on a 7 percent, $38,500 bond used to help finance the project. The annual operating costs for the ponds in the Salt Lake County, Utah project were estimated at $560 for the wet pond and $200 for the dry pond.

The costs of the structural control alternatives to control discharge to the ocean in Myrtle Beach, South Carolina, were presented in detail and are valid estimates of the costs that will be incurred if one of them is constructed.

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6 Collection of Economic Data From Nationwide Urban Runoff Program Projects - Final Report, April 7, 1982, EPA Contract No. 68-01-5052. Detailed cost data provided by the projects are included in the appendices of this Report to show how the various projects prepared the data for submission.

The 1980 construction cost estimates ranged from $32,849,200 to $50,973,500, and the annual operating cost estimates ranged from $3,735,400 to $5,301,900. The cost of the public education program at Salt Lake County, Utah, was estimated at $1,550. The project will report the actual cost of the program upon its completion.

## Revenue Analysis

The revenue analysis identifies the funding sources needed to match the estimated cost for control activities by participating agencies. This analysis is important because it ensures adequate funding to implement the technical solution to an urban runoff problem.

There are three categories of funding that are typically used to pay for runoff control: Federal and State funds, local public funds, and private funds. These sources include a variety of different financing mechanisms, each with advantages and disadvantages. The use of any or a combination of these sources requires consideration regarding:

- Revenue adequacy - Will funds be available in the long- and short-term?

- Equity - Are the beneficiaries of the control program paying their full share?

- Economic efficiency - Is the charge that is assessed equal to the social cost of the program?

- Administrative simplicity - Can the funds be managed and directed to the control program without significant administrative problems?

## Ability-to-Pay Analysis

The ability-to-pay analysis evaluates the implementing agencies' and the individual user's ability to pay for the proposed program by determining how reasonable a proposed revenue program is in terms of its overall impact on the community as a whole as well as on individual residents.

For a given revenue source, the additional burden of the program is expressed as a percentage of the base costs. For example, if the proposed program is to be financed by property taxes and it adds $.50 to a $1,000 tax bill, the additional tax burden is .05 percent. In this instance, it would appear that the homeowner's ability to pay is quite high.

An important factor to remember is that programs to control urban runoff are not the only programs that are placing a burden on the people or institutions who must support them. Hence, the cost of a control program may not be excessive but cannot be imposed because ability to pay has already been exceeded due to other projects.

## Sensitivity Analysis

The sensitivity analysis identifies the extent to which local ability to pay varies with changes in the assumptions used to estimate costs and revenues. Major assumptions that influence costs and revenues are: phasing of capital improvement, anticipated local funding requirements, rate of inflation, growth rate, and local fee policies.

The first step in this analysis is to determine a range of values for key cost and revenue assumptions that could occur during the program. (For example, inflation may vary between 5 percent and 15 percent.) The ability-to-pay analysis is then repeated using the high and low values for these assumptions. The final step is to evaluate the changes in burden with "best-" and "worst-" case situations in comparison with burden under the "most likely" assumption.

The purpose of this analysis is to identify control programs that are least vulnerable to changing conditions. It also helps to make the planner aware of best- and worst-case scenarios so that contingency plans can be developed to cope with such events.

## Indirect Impact Analysis

The indirect impact analysis is an assessment of the costs and benefits that are not directly attributable to a proposed program. These costs and benefits can be economic, social, and/or environmental. Quantifying the indirect impacts of a program is usually quite difficult, so the planner generally resorts to qualitative measurement.

## An Example: Planning an Educational Program

To illustrate further the process of identifying and resolving the financial and institutional issues connected with implementation of an urban runoff control program, the following spells out the steps involved in evaluating one control approach applicable in already developed areas. The example chosen is an educational program to inform citizens, industry, and public agencies of the problems caused by runoff-borne lawn and garden chemicals, oil and chemical residuals from industrial yards, and pesticides, herbicides, and fertilizer from parks and golf courses.

In this example, the activities would include: development of an informational brochure, including printing and distribution, and maintenance of an information center. In Figure 4-6, the institutional characteristics needed to accomplish these activities are compared with the capabilities of existing agencies. The matrix shows that the County Department of Pollution Control could provide the technical input to the Public Information Center to write the brochure. The Council of Governments might coordinate the effort and assume overall responsibilities for getting the job done.

| INSTITUTIONAL CHARACTERISTICS NEEDED | AGENCIES | | | | | |
|---|---|---|---|---|---|---|
| | STATE | COUNCIL OF GOVERNMENTS | DEPARTMENT OF POLLUTION CONTROL | DEPARTMENT OF PLANNING | PUBLIC INFORMATION CENTER | CHAMBER OF COMMERCE |
| • COMMITMENT TO PROGRAM GOALS | * | * | * | * | * | * |
| • WORKING KNOWLEDGE OF EACH WASTE CONTRIBUTION TO THE RUNOFF PROBLEM | * | * | * | * | | |
| • ABILITY TO WRITE CLEAR AND CONCISE INFORMATION FOR THE PUBLIC | | | | | * | |
| • ABILITY TO PRINT AND AND DISTRIBUTE BROCHURE | | | | * | | * DISTRIBUTE TO INDUSTRY |
| • STAFF TO RECEIVE FOLLOWUP CALLS | | * | | | | |
| • ABILITY TO ACCEPT FUNDS FROM SEVERAL AGENCIES TO PAY FOR THE PROGRAM | | * | | | | |

83-2061-44

Figure 4-6. Institutional Assessment for Educational Program to Control Chemical Substances

Cost Analysis. Cost analysis determines the additional funds needed to implement a control alternative, including capital improvements and operation and maintenance. Additional administrative costs are less significant because most of these projects are undertaken by a public agency that is already performing the function to some extent.

Capital cost estimates are best prepared by the water quality planner with the assistance of the municipal engineer and in some cases his/her outside engineering advisor. These estimates identify all costs related to the purchase of a new facility or piece of equipment for a project and may require some research into vendor prices and bids on similar projects around the country. For programs which require changes to existing practices (street sweeping, etc.), the cost attributable to the water quality program is the incremental cost of the program.

Ultimately, the cost analysis is used to identify the least-cost method(s) for reducing pollution problems. It is important to remember that all costs associated with a given program must be considered. It is incorrect to assume that educational efforts, for example, are provided at no additional cost.

As an example of a cost analysis, a possible budget sheet for the educational program for the current year is presented in Figure 4-7.

| | AGENCIES | | | | | |
|---|---|---|---|---|---|---|
| ACTIVITIES | STATE | COUNCIL OF GOVERNMENTS | DEPARTMENT OF POLLUTION CONTROL | DEPARTMENT OF PLANNING | PUBLIC INFORMATION CENTER | TOTAL |
| 1. DEVELOP BROCHURE | | | | | $13,000 | $13,000 |
| 2. PRINT BROCHURE | | | | $1,500 | | $ 1,500 |
| 3 DISTRIBUTE BROCHURE | | | | $ 800 | | $ 800 |
| 4. CONDUCT INFORMATIONAL MEETINGS | $2,000 | $ 5,500 | $2,000 | | | $ 9,500 |
| 5. STAFF FOLLOWUP FOR PROGRAM | | $24,000 | | | | $24,000 |
| TOTAL | $2,000 | $29,500 | $2,000 | $2,300 | $13,000 | $48,800 |

83-2061-45

Figure 4-7. Cost Analysis for Educational Program to Control Chemical, Herbicide, Fertilizer and Pesticide Runoff

Revenue Analysis. After the program cost estimate is prepared, the potential sources of revenue are analyzed. There are several critical factors in analyzing revenue for urban runoff programs including:

- Cost/Revenue Balance - Will the revenues be sufficient to cover the costs on an annual basis?

- Equitable Allocation of Costs to Different Groups - Do those who contribute to the problem pay their fair share? Do those who benefit from the program pay their fair share?

- Revenue Agreement - Do groups understand their participation in a program and its revenue formula? Have written agreements which define the cost allocation procedure been prepared ?

Revenue analysis will vary with the type of control approach selected. The critical factor in the revenue analysis is the identification of each entity that will provide revenues and the development of an understanding by that entity of the problem, the control approach, and its share of the cost.

Ability-to-Pay Analysis. Most of the costs to control runoff from developed areas are imposed on the general public or the benefiting population as a new and additional governmental expense. The ability-to-pay analysis evaluates this increased burden on the local community as a percentage of property taxes, average income, property evaluation, or other appropriate measures.

Figure 4-8 illustrates an ability-to-pay analysis for the educational program example. The key parameters to determine homeowners' ability to pay in this case are the cost of the program per household, cost as a percentage of average annual household income, and cost as a percentage of property taxes.

| | | |
|---|---|---|
| A. TOTAL PROGRAM COST (ONE-YEAR PROGRAM) | $48,000 | |
| B. NUMBER OF HOUSEHOLDS AFFECTED | 19,000 | |
| C. COST PER HOUSEHOLD (A DIVIDED BY B) | | $2.57 |
| D. MEDIAN HOUSEHOLD INCOME | $14,700 | |
| E. COST AS A % OF MEDIAN HOUSEHOLD INCOME (C DIVIDED BY D TIMES 100) | | .02% |
| F. AVERAGE ANNUAL PROPERTY TAXES | $ 1,200 | |
| G. COST AS A % OF PROPERTY TAXES (C DIVIDED BY F TIMES 100) | | .21% |

CONCLUSION: PROGRAM APPEARS TO NOT PLACE EXCESSIVE BURDEN ON LOCAL HOMEOWNERS

83-2061-46

Figure 4-8. Ability to Pay Analysis for Educational Program to Control Chemical, Herbicide, Fertilizer and Pesticide Runoff

Sensitivity Analysis. The sensitivity analysis will vary depending upon the revenue mechanism and program selected for implementing a proposed program. The most common revenue mechanisms for programs controlling runoff from developed areas are general funds and fees. Analyzing the sensitivity of general revenues requires a review of past collections relative to key parameters--inflation, housing starts, collection rates, capital improvements, and so on. Collections are then projected for worst and best case scenarios.

An additional consideration in the sensitivity analysis is revenue requirements. This relates to phasing a program, either handling capital improvements or starting a program on a limited basis with expansion to come in later years. For any one program, numerous options exist for staggering cash flows, and different scenarios should be developed to assess their impact on the program as part of the sensitivity analysis.

Indirect Impact. The indirect impact of a runoff control program for developed areas are extremely difficult to quantify. Educational programs will raise community awareness regarding the impacts of local activities on water pollution. Other indirect impacts from control programs may relate to recreational benefits, local improvements in quality of life, and increased tourism.

## RELATIONSHIP BETWEEN NURP AND WQM PLANS

Of the locations selected for projects under the NURP effort, some 80 percent had state-approved (i.e., certified by the Governor) water quality management (WQM) plans with elements which addressed urban runoff. For 5 of these locations, the NURP project constituted the urban runoff element of the plan. For the other locations, however, the original 208 effort was unable to develop the necessary information on either water quality effects or performance of best management practices (BMPs) to justify structuring formal implementation plans for urban runoff control. Consequently, the typical WQM plan elements dealing with urban runoff identified the need for further study, usually specifying problem assessment and BMP performance evaluation. These elements became the focal points of the activities funded by NURP.

The WQM plans for the remaining 20 percent of the locations which participated in the NURP program did not contain a specific urban runoff element. Presumably this was due to time and resource constraints in relation to other issues which were assigned higher priorities in planning efforts. In these cases, the NURP projects provided the opportunity to address a water quality issue not adequately addressed in the original 208 planning studies.

Over two-thirds of the NURP project locations reported that NURP findings and recommendations have or will be incorporated in the next annual update of their formal WQM plans. The remainder generally indicate that they expect the planning issues to be addressed at the local level or that NURP results will support planning and implementation activities, even though they do not anticipate formal incorporation in WQM plans at this time.

Over half of the NURP project locations report either active or planned implementation efforts based on the results of NURP. Thirty percent indicated that no implementation is being planned because the need for or value of urban runoff control was not demonstrated. The balance (20 percent) of the NURP locations suggest that while implementation activities are not currently planned, they expect NURP results to influence future deliberations on this issue.

# CHAPTER 5
# METHODS OF ANALYSIS

## INTRODUCTION

This chapter identifies and briefly discusses the methods adopted to assemble and analyze the large data base developed by the NURP projects and also provides the methods employed to develop and interpret results. The chapter is structured according to the three prime areas of program emphasis; (1) characteristics of pollutants in urban runoff, (2) water quality effects of urban runoff discharges including water quality criteria/standards violations and impairment or denial of beneficial uses of receiving water bodies, and (3) the effectiveness of control measures to reduce pollutant loads.

The procedures employed in this assessment were designed to provide generalized results and findings about urban runoff issues of interest for nationwide use. This national perspective, and the need to consider the fundamental variability of urban runoff processes, has prompted some significant advancements in the application of statistical methods and models. The basic methods used were, however, largely developed under different EPA efforts, many under the sponsorship of the Office of Research and Development, or other programs. In some cases, similar or equivalent procedures were applied in individual NURP projects; in other cases, methods adopted by individual projects in response to local needs and interests were different. Where possible, comparisons have been made between either detailed results, or conclusions drawn from such results, as derived from both local and national perspectives.

The descriptions provided in this chapter are brief and intended to communicate the technical framework upon which the results and conclusions are based. More detailed information on the methods and techniques are contained in other documents developed by NURP. Pertinent NURP reports cover, in separate volumes, probabilistic methods for analyzing water quality effects, detention and recharge basins for control of urban stormwater quality, and street sweeping for control of urban stormwater quality. The Data Management Procedures Manual, another of the project documents, is an additional source of information on details of the analysis methods utilized.

Because field measurements and sampling formed one of the most important information sources, it was essential that the monitoring and analysis programs produce consistent and sound data. Accordingly, NURP required that all projects adopt Quality Assurance/Quality Control elements as integral parts of their work plans. Key components of these plans include the following:

- Program Coordination. Projects were required to designate a QA/QC coordinator, responsible for the entire QA/QC effort.

- Field Quality Assurance. Guidance was provided to the projects for all key aspects of the data collection process.

- Laboratory Quality Assurance. A manual prepared by EPA's Environmental Monitoring and Support Laboratory was provided to all projects and contained analytical quality control information.

- Data Management. A manual entitled "Data Management Procedures" was provided to all projects and covered such topics as data formatting, data reduction, and some analysis.

- Data Analysis. To encourage innovative approaches and responsiveness to local conditions, uniform methods of data analysis were not stressed. Technical guidance and mandatory review of analytical procedures were provided.

RUNOFF POLLUTANT CHARACTERISTICS

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stantial component of the individual NURP projects was the acquisition subsequent analysis) of a data base for a number of storm events, conng of precipitation and the resulting quantity and quality of runoff a number of local urban catchments. One of the principal EPA objectives e analysis of these data has been to develop a concise summary of the cteristics of urban runoff. There are a number of questions concerning runoff characteristics which need to be addressed for water quality ing purposes, including what are the appropriate measures of the statischaracteristics of urban runoff (e.g., population distribution, central ncy, variability, etc.)? Do distinct subpopulations exist and what are characteristics? Are there significant differences in data sets ed according to locations around the county (geographic zones), land season, rainfall amount, etc.? How may these variations be recognized? s the most appropriate manner in which to extrapolate the existing data to locations for which there are no or limited measurements? Though questions cannot be fully answered given the current state of knowledge ning urban runoff, these are the types of issues addressed by the ls described in this chapter and the results presented in Chapter 6.

rincipal thrust of the individual NURP projects, and thus this nationassessment report, was the characterization of what has been adopted as lard Pollutants" of primary concern in urban runoff. These include , oxygen consuming constituents, nutrients, and a number of the more ly encountered heavy metals. The methods used to characterize these rd pollutants are described under a separate heading below.

roximately two-thirds of the NURP projects the occurrence of compounds s list of "Priority Pollutants" was investigated. This program element so described under a separate heading below. A number of additional have also been addressed in the program. These are briefly discussed below because they relate closely to the general issue of pollutant characteristics. These include the following:

- Soluble vs Particulate Pollutant Forms. The distribution of soluble and particulate forms of a pollutant in urban runoff (particularly metals and nutrients) was examined in both the standard conventional pollutant and priority pollutant aspects of the study because certain beneficial use effects depend strongly on the form in which the contaminant is present. The priority pollutant program additionally determined "Total Recoverable" fractions, corresponding to contaminant forms used in EPA's published toxic criteria guidelines.

- Coliform Bacteria. Fecal coliform bacteria counts (and in some cases total coliform and fecal streptococcus as well) in urban runoff were monitored during a significant number of storms by seven of the NURP projects. Though the data base for bacteria is restricted, useful results are provided in Chapter 6.

- Wetfall/Dryfall. As part of program elements designed to examine sources of pollutants in urban runoff, a number of projects operated atmospheric monitoring stations for characterizing pollutant contributions from precipitation (wetfall) and from dry weather deposition (dryfall). Results of this work are reported in individual project reports and not included herein.

### Standard Pollutants

The following constituents were adopted as standard pollutants characterizing urban runoff:

TSS - Total Suspended Solids
BOD - Biochemical Oxygen Demand
COD - Chemical Oxygen Demand
TP - Total Phosphorus (as P)
SP - Soluble Phosphorus (as P)
TKN - Total Kjeldahl Nitrogen (as N)
$NO_{2+3}$-N - Nitrite + Nitrate (as N)
Cu - Total Copper
Pb - Total Lead
Zn - Total Zinc

The list includes pollutants of general interest which are usually examined in both point and nonpoint source studies and includes representatives of important categories of pollutants--namely solids, oxygen consuming constituents, nutrients, and heavy metals.

The pollutant concentrations found in urban runoff vary considerably, both during a storm event, as well as from event to event at a given site and from site to site within a given city and across the country. This variability is the natural result of high variations in rainfall intensity and occurrence, geographic features that affect runoff quantity and quality, and so on. Considering this situation, a measure of the magnitude of the urban runoff pollution level and methods for characterizing its variability were needed. The event mean concentration (EMC), defined as the total constituent mass discharge divided by the total runoff volume, was chosen as the primary measure of the pollutant load. The rationale for adopting the EMC for characterizing urban runoff is discussed in the receiving water effects section of this chapter as well as in subsequent chapters. Event mean concentrations were calculated for each event at each site in the accessible data base. If a flow-weighted composite sample was taken, its concentration was used to represent the event mean concentration. Where sequential discrete samples were taken over the hydrograph, the event mean concentration was determined by calculating the area under the loadograph (the curve of concentration times discharge rate over time) and dividing it by the area under the hydrograph (the curve of runoff volume over time). Details of the calculation procedure have been described in the Data Management Procedures Manual. For the purpose of determining event mean concentrations, rainfall events were defined to be separate precipitation events when there was an intervening time period of at least six hours without rain.

A statistical approach was adopted for characterizing the properties of EMCs for standard pollutants. Standard statistical procedures were used to define the probability distribution, central tendency (a mean or median) and spread (standard deviation or coefficient of variation) of EMC data. EMC data for each pollutant from all storms and monitoring sites were complied in a central data base management system at the National Computer Center. The SAS computer statistical routines and other standard statistical methods were used to explore and characterize the data. The statistical methods used are, for the most part, not explained in this report since these are readily available in the literature. Nor are the operations of the SAS routines, which are available at most computer centers.

The underlying probability distribution of the EMC data was examined and tested by both visual and statistical methods. With relatively few isolated exceptions, the probability distribution of EMCs at individual sites can be characterized by lognormal distributions. Given this, concise characterization of the variable urban runoff characteristics at each of the sites is defined by only two values, the mean or median and the coefficient of variation (standard deviation divided by mean). Because the underlying distributions are lognormal, the appropriate statistic to employ for comparisons between individual sites or groups of sites is the median value, because it is less influenced by the small number of large values typical of lognormal distributions and, hence, is a more robust measure of central tendency. However, for comparisons with other published data which usually report average values and for certain computations and analyses (e.g., annual mass loads), the mean value is more appropriate.

Relationships among a number of statistical properties of interest are easily determined when distributions are lognormal. Figure 5-1 illustrates some relationships for lognormal distributions. In (a) the frequency distributions of two variable data sets which are log-normal and have the same median are shown. The log transforms of the data result in normal bell

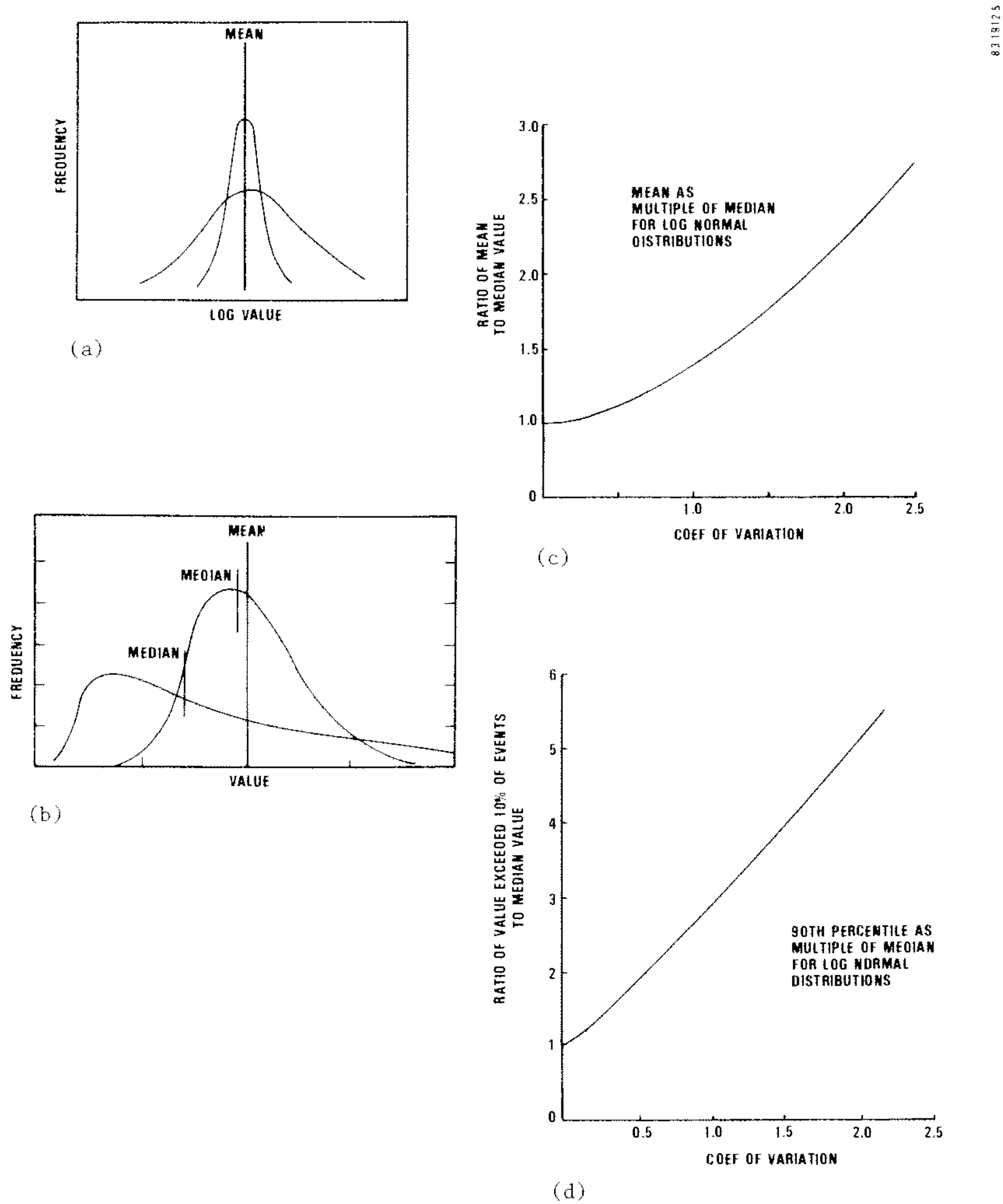


Figure 5-1. Lognormal Distribution Relationships

shaped distributions; more variable data (higher coefficient of variation) result in a greater spread. Frequency histograms prepared using untransformed data values produce skewed distributions, as shown by (b) which illustrates two data sets which have the same arithmetic mean. The effect of coefficient of variation is shown as well as the relation between mean and median for lognormal distributions. An established relationship exists between median and mean, as shown by (c) and described by:

$$\frac{\text{Mean}}{\text{Median}} = \sqrt{1 + (\text{Coef Var})^2}$$

When a distribution is known to be lognormal the best estimate of the population mean is that derived from the lognormal relationships. For small samples it can be expected to be different than the result of a straight arithmetic averaging of sample data; the two estimates of the mean will give similar values when the number of samples is very large.

In addition, the expected value at any probability or frequency of occurrence ($X_\alpha$) can be determined by:

$$X_\alpha = \exp\,(\mu_{\ln x} + Z_\alpha\, \sigma_{\ln x})$$

where:

$Z_\alpha$ = the standard normal probability

$\mu_{\ln x}$ = mean of log-transformed data

$\sigma_{\ln x}$ = standard deviation of log-transformed data

$X_\alpha$ can be expressed as a ratio to the median value by the following equation which defines the ratio in terms of the coefficient of variation

$$\frac{X_\alpha}{\text{Median}} = \exp\,(Z_\alpha \sqrt{\ln\,(1 + (\text{Coef Var})^2)}).$$

This relationship is shown by (d) for 90th percentile values (10 percent exceedance, $Z_\alpha = 1.2817$).

The establishment of the fundamental distribution as lognormal, and the availability of a sufficiently large sample population of EMCs to provide reliable derived statistics, has a number of benefits:

- Concise summaries of highly variable data can be developed.
- Comparisons of results from different sites, events, etc., are convenient and are more easily understood.

- Statements can be made concerning frequency of occurrence. One can express how often values will exceed various magnitudes of interest.

- A more useful method of reporting data than the use of ranges is provided; one which is less subject to misinterpretation.

- A framework is provided for examining "transferability" of data in a quantitative manner.

### Priority Pollutants

In cooperation with EPA's Monitoring and Data Support Division (MDSD), a special study element was built into two-thirds of the NURP projects (20 of 28) to identify which of the compounds on EPA's list of "Priority Pollutants" are found in urban runoff, and the concentrations at which they occur. The base effort collected 121 samples of urban runoff which were analyzed for priority pollutants. A supplementary special metals study secured 147 samples. Methods utilized in this study element are described in the following report which covers this activity:

> "NURP Priority Pollutant Monitoring Project: Summary of Findings", December 1983; EPA Monitoring and Data Support Division, Office of Water Regulations and Standards, Washington, D.C.

In addition to the above special study, as previously mentioned, most NURP projects monitored selected heavy metals (principally total copper, total lead, and total zinc) in their routine monitoring programs. Summaries of these data are presented in Chapter 6.

### Hydrometeorological Statistics

Consistent with the adoption of a storm "event" as the fundamental time scale used in the analysis of data and the interpretation of effects, rainfall data were analyzed to define "event" statistics for a significant number of locations throughout the country. The SYNOP program was employed for developing the statistical parameters of rainfall intensity, duration, volume, and interval between storm events. This program has been detailed in the NURP "Data Management Procedures Manual."

In addition to rainfall, rainfall-runoff relationships were characterized for monitored storm events. The runoff coefficient, defined as the ratio of runoff volume to rainfall volume, was computed, and effects of such catchment characteristics as land use and imperviousness were investigated. Long-term streamflow records for numerous stations across the country were also analyzed to characterize regional trends.

## RECEIVING WATER QUALITY EFFECTS

### General

A number of individual NURP projects examined the site-specific impacts of urban runoff on water quality for a variety of beneficial uses and receiving water types. These results provide important information on the extent to which urban runoff constitutes a "problem" as well as "ground truth" measurements against which more generalized techniques can be compared. Methodologies employed in these local studies vary and are described in the individual project reports. Relevant site-specific project results are cited in Chapter 9.

Receiving water impact analyses cannot be readily generalized because there is a high degree of site-specificity to the important factors. The type of beneficial use dictates the pollutants which are of principal concern; the type of water body (e.g., stream, lake, estuary) determines how receiving water quality responds to loads; and physical characteristics (e.g., size, geometry, flows) have a major influence on the magnitude of response to a particular load.

Despite the inherent limitations of a set of generalized receiving water impact analyses, a screening level analysis was considered a necessary element for a nationwide assessment of the general significance of urban runoff in terms of water quality problems, especially adverse effects on beneficial uses. Accordingly, a set of analysis methodologies were adopted and utilized as screening techniques for characterizing water quality effects of urban runoff loads on receiving water bodies. A key requirement was to delineate the severity of water quality problems by quantifying the magnitude, and in the case of intermittent loads, the frequency of occurrence of water quality impacts of significance. These procedures are identified and described briefly below. Significant technical aspects are detailed further in the supplementary NURP report which addresses the receiving water impact analysis methodology.

It was not possible to perform a "National Assessment" in the usual sense of the term. NURP has determined that it is not realistic (if the basis is effect on beneficial use of a water body) to estimate the total number of water quality problem situations in the nation which result from urban stormwater runoff or the cost of control which would ultimately result. The available analysis methods do permit an assessment of a different kind. NURP applied the analysis procedures as a screening type analysis to define the conditions under which problems of different types are likely or unlikely to occur. From the results of these screening analyses, NURP has drawn inferences and made general statements (Chapters 7 and 9) on the significance of urban runoff. Where it has been possible or practical to do so, these general screening analyses were applied to local situations which exist within certain of the individual NURP projects. Comparisons were made between specific water quality effects or broader conclusions relative to problems derived from both local analysis and general screening methods.

## Time Scales of Water Quality Impacts

There are three types of water quality impacts associated with urban runoff. The first type is characterized by rapid, short-term changes in water quality during and shortly after storm events. Examples of this water quality impact include periodic dissolved oxygen depressions due to oxidation of contaminants, or short-term increases in the receiving water concentrations of one or more toxic contaminants. These short-term effects are believed to be an important concern and were the prime focus of the NURP analysis.

Long-term water quality impacts, on the other hand, may be caused by contaminants associated with suspended solids that settle in receiving waters and by nutrients which enter receiving water systems with long retention times. In both instances, long-term water quality impacts are caused by increased residence times of pollutants in receiving waters. Other examples of the long-term water quality impacts include depressed dissolved oxygen caused by the oxidation of organics in bottom sediments, biological accumulation of toxics as a result of up-take by organisms in the food chain, and increased lake entrophication as a result of the recycling of nutrients contributed by urban runoff discharges. The long-term water quality impacts of urban runoff are manifested during critical periods normally considered in point source pollution studies, such as summer, low stream flow conditions, and/or during sensitive life cycle stages of organisms. Since long-term water quality impacts occur during normal critical periods, it is necessary to distinguish between the relative contribution of urban runoff and the contribution from other sources, such as treatment plant discharges and other nonpoint sources. A site-specific analysis is required to determine the impact of various types of pollutants during critical periods, and this aspect of urban runoff effects was not addressed in detail in NURP.

A third type of receiving water impact is related to the quantity or physical aspects of flow and includes short-term water quality effects caused by scour and resuspension of pollutants previously deposited in the sediments. This category of impact was not addressed by NURP, in general, although one project provides some information.

As indicated previously, the first type of change in water quality associated with discharges from urban runoff is characterized by short-term degradation during and shortly after storm events. The rainfall process is highly variable in both time and space. The intensity of rainfall at a location can vary from minute to minute and from location to location. Phenomena which are driven by rainfall such as urban runoff and associated pollutant loadings are at least as variable. Short term measurements, on a time scale of minutes, to define rainfall, the runoff flow hydrograph, and concentrations of contaminants (pollutographs) feasibly can be taken at only a rather limited number of locations. These measurements have usually been employed in an attempt to refine or calibrate calculation procedures for estimating runoff flows and loads. Most urban areas contain a network of drainage systems which collect and discharge urban runoff into one or more receiving water bodies. Since the rainfall, runoff, and pollutant loads vary in both time and space, it is impossible to determine by calculation or measurement the very short time scale (minute-to-minute) changes in water quality of a receiving water and assign the changes to specific sources of runoff. Although very short duration exposures (on the order of minutes) to very high concentrations of toxics can produce environmental damage (mortality or sublethal effects) to aquatic organisms, it is likely that exposures on the order of hours have the highest possibility of causing adverse environmental impacts. This results, in part, from the smoothing obtained by mixing numerous sources which have high frequency (short-term) variability.

In view of the above discussion, the time scale used by NURP for analysis of short-term receiving water impacts is the rainfall event time scale which is on the order of hours. To represent the average concentration of pollutants in urban runoff produced during such an event, NURP used the event mean concentration.

## Criteria/Standards and Beneficial Use Effects

As discussed in previous chapters, three definitions have been adopted to assess receiving water problems associated with urban runoff; (1) impairment or denial of beneficial use, (2) violation of numerical criteria/standards, and (3) local perception of a problem. The procedures and methods employed in the NURP assessment focus on the first two problem definitions. A framework for identifying target receiving water concentrations associated with the criteria standards and beneficial use problems are provided below. The third problem type, local perception of a problem and degree of concern cannot be addressed by these quantitative procedures.

The analysis methods employed make it possible to project water quality effects caused by intermittent, short-term urban runoff discharges. Where appropriate, these effects are expressed in terms of the frequency at which a pollutant concentration in the water body is equalled or exceeded. However, if the basis for determining the significance of such water quality impacts (and hence the need for control) is taken to be the effect such receiving water concentrations have on the impairment or denial of a specific beneficial use, then it is necessary to go one step further. A basis is required for judging the degree to which a particular water quality impact constitutes an impairment of a beneficial use. With intermittent pollutant discharges, effects are variable and are best expressed in terms of a probability distribution from which estimates can be made of the frequency with which effects of various magnitude occur.

There is a rather broad consensus that existing water quality criteria, and water uses based on such criteria, are most relevant when considered in terms of continuous exposures (ambient conditions). Even where continuous discharges are involved, there has been discussion and debate as to whether a particular criterion should be interpreted as some appropriate "average" condition or a "never-to-exceed" limit. The basic issue is whether the more liberal interpretation will provide acceptable protection to the beneficial use for which the criterion in question has been developed. The only reason such distinctions become an issue is because the practical feasibility or relative economics, or both, are sufficiently different that one is encouraged to question whether the more restrictive interpretation is overly (or even excessively) conservative in terms of providing protection for the associated beneficial use.

The issue (i.e., whether traditional ambient criteria are excessively conservative measures of conditions which provide reasonable assurances of protection for a beneficial use when exceeded only intermittently) is particularly appropriate in the case of urban storm runoff. Analysis of rainfall records for a wide distribution of locations in the nation indicates that, even in the wetter parts of the country, urban runoff events occur only about 10 percent of the time. There are regional and seasonal differenc but typical values for annual average storm characteristics in the easte half of the United States are:

| | Average (Hours) | Median (Hours) | 90th Percentile (Hours) |
|---|---|---|---|
| Storm Duration | 6 | 4.5 | 15 |
| Interval Between Storm Mid-Points | 80 | 60 | 200 |

These estimates are based on results from an analysis of long-term rainfa records for 40 cities throughout the country. Median and 90th percenti values are derived from data mean and variance based on a gamma distributic which has been shown to characterize the underlying distribution of stc event parameters quite well.

In the semi-arid regions of the western half of the country, average stc durations tend to be comparable to the above, but average intervals betwe successive storms increase substantially (two to four fold) and are high seasonal. With urban storm runoff, therefore, one is dealing with polluta discharges which occur over a period of a few hours every several days more or after long dry periods. In advective rivers and streams, the wat mass influenced by urban runoff tends to move downstream in relatively di crete pulses. Because of the variability in the magnitude of the polluta loads from different storm events, only a small percentage of these puls have high pollutant concentrations.

There are currently no formal "wet weather" criteria and, thus, no general accepted way intermittent exposures having time scale characteristics typic of urban runoff can be related to use impairment. In the belief that would be inappropriate to ignore such considerations in a general evaluati of urban runoff, NURP has developed estimates for concentration levels whi result in adverse impacts on beneficial use when exposures occur intermi tently at intervals/durations typical of urban runoff. These "effec levels" were used to interpret the significance of the variable, intermitte water quality impacts of urban runoff. It should be understood that the effects levels do not represent any formal position taken by EPA, but a simply the most reasonable yardsticks available to meet the immediate nee of the evaluation of urban runoff. As used in the screening analysis proc dures, alternative values for "effects levels" may be readily substitut when either more accurate estimates can be made, or more (or less) conser tive approaches are indicated in view of the importance of a particular wat body or beneficial use.

Table 5-1 summarizes information on water quality criteria for a number contaminants routinely found in urban storm runoff. The data present include:

- Water quality criteria for substances on EPA's priority pollutant list (45 FR No. 79318, 11/28/80). These criteria provide

## TABLE 5-1. SUMMARY OF RECEIVING WATER TARGET CONCENTRATIONS USED IN SCREENING ANALYSIS - TOXIC SUBSTANCES (ALL CONCENTRATIONS IN MICROGRAMS/LITER, µg/ℓ)

| Contaminant | Water Hardness mg/l (as Ca $CO_3$) | Freshwater Aquatic Life | | Saltwater Aquatic Life | | Human Ingestion | Estimated Effect Level For Intermittent Exposure | |
|---|---|---|---|---|---|---|---|---|
| | | 24 Hour | Max | 24 Hour | Max | (1) | Thresh-hold | Significant Mortality |
| Copper | 50 | 5.6 | 12 | 4.0 | 23 | NP | 20 | 50 - 90 |
| | 100 | 5.6 | 22 | 4.0 | 23 | | 35 | 90 - 150 |
| | 200 | 5.6 | 42 | 4.0 | 23 | | 80 | 120 - 350 |
| | 300 | 5.6 | 62 | 4.0 | 23 | | 115 | 265 - 500 |
| Zinc | 50 | 47 | 180 | 58 | 170 | NP | 380 | 870 - 3,200 |
| | 100 | 47 | 321 | 58 | 170 | | 680 | 1,550 - 4,500 |
| | 200 | 47 | 520 | 58 | 170 | | 1,200 | 2,750 - 8,000 |
| | 300 | 47 | 800 | 58 | 170 | | 1,700 | 3,850 - 11,000 |
| Lead | 50 | 0.75 | 74 | | | | 150 | 350 - 3,200 |
| | 100 | 3.8 | 172 | (25) | (670) | 50.0 | 360 | 820 - 7,500 |
| | 200 | 12.5 | 400 | | | | 850 | 1,950 - 17,850 |
| | 300 | 50.0 | 660 | (C) | (A) | | 1,400 | 3,100 - 29,000 |
| Chrome (+3) | 50 | | 2,200 | | | | | |
| | 100 | (44) | 4,700 | N.P. | (10,300) | 170.00 | 8,650 | |
| | 300 | (C) | 15,000 | | (A) | | | |
| Chrome (+6) | - | 0.29 | 21.0 | 18 | 1260 | 50.0 | | |
| Cadmium | 50 | 0.01 | 1.5 | | | | 3 | 7 - 160 |
| | 100 | 0.02 | 3.0 | 4.5 | 59.0 | 10 | 6.6 | 15 - 350 |
| | 300 | 0.08 | 9.6 | | | | 20 | 45 - 1,070 |
| Nickel | 50 | 56 | 1,090 | | | | | |
| | 100 | 96 | 1,800 | 7.1 | 140.0 | 13.4 | | |
| | 300 | 220 | 4,250 | | | | | |

NOTES:

- NP = No criteria proposed.
- Some toxic criteria are related to Total Hardness of receiving water. Where this applies, several values are shown. Other values may be calculated from equations presented in EPA's Criteria Document (Federal Register, 45,231, November 28, 1980). Where a single value is shown, water hardness does not influence toxic criteria.
- Concentration values shown within parentheses ( ) are not formal criteria values. They reflect either chronic (C) or acute (A) toxicity concentrations which the EPA toxic criteria document indicated have been observed. Values of this type were reported where the data base was insufficient (according to the formally adopted guidelines which were used in developing the criteria) for EPA to develop 24 hour and Max values.
- Note (1): The "Human Ingestion" criteria developed by the EPA Toxic Criteria documents are indicated to relate to ambient receiving water quality. The Drinking Water Criteria relate to finished water quality at the point of delivery for consumption.
- Estimated Effects levels reflect estimates of the concertration levels which would impair beneficial uses under the kind of exposure conditions which would be produced by Urban Runoff. They are an estimate of the relationship between continuous exposure and intermittent, short duration exposures (several hours once every several days). Threshold concentrations are those estimated to cause mortality of the most sensitive individual of the most sensitive species.

  Significant Mortality concentrations are shown as a range which reflects 50 percent of the most sensitive species and mortality of the most sensitive individual of the 25th percentile species sensitivity.

an extensive set of numerical values derived from bioassay studies.

- Estimates of "effects levels" which are suggested by NURP analysis to be relevant for the intermittent exposures characteristic of urban runoff.

By incorporating the numerical values for EPA's ambient water quality criteria and the concentration levels suggested by NURP for intermittent effects in the same table (or on the same graph in Chapter 7), a convenient, concise comparison is provided of the practical implications of applying one or the other as the yardstick for judging the protection or impairment of water use. The two sets of numerical values thus provide measures for two of the three options for defining a problem: violation of criteria or actual impairment of a beneficial use.

Comparison of the pollutant concentrations in urban runoff showing the frequency and magnitude of exceedance of ambient criteria and intermittent effects levels provides a qualitative sense of the control requirements (and implications regarding costs) attendant on the adoption of either problem definition as the operative one.

Rivers and Streams

The approach adopted to quantify the water quality effects of urban runoff for rivers and streams focuses on the inherent variability of the runoff process. What occurs during an individual storm event is considered secondary to the overall effect of a continuous spectrum of storms from very small to very large. Of basic concern is the probability of occurrence of water quality effects of some relevant magnitude.

To consider the intermittent and variable nature of urban runoff, a stochastic approach was adopted. The method involves a direct calculation of receiving water quality statistics using the statistical properties of the urban runoff quality and other relevant variables. The approach uses a relatively simple model of the physical behavior of the stream or river (as compared to many of the deterministic simulation models). The results are therefore an approximation, but appropriate as a screening tool.

The theoretical basis of the technique is quite powerful as it permits the stochastic nature of runoff process to be explicitly considered. Application is relatively straightforward, and the procedure is relevant to a wide variety of cases. These attributes are particularly advantageous given the national scope of the NURP assessment. The details of the stochastic method are summarized and presented below.

Figure 5-2 contains an idealized representation of urban runoff discharges entering a stream. The discharges usually enter the stream at several locations but are considered here to be adequately represented by an equivalent discharge flow which enters the system at a single point.

Receiving water concentration (CO) is the resulting concentration after complete mixing of the runoff and stream flows and is interpreted as the mean

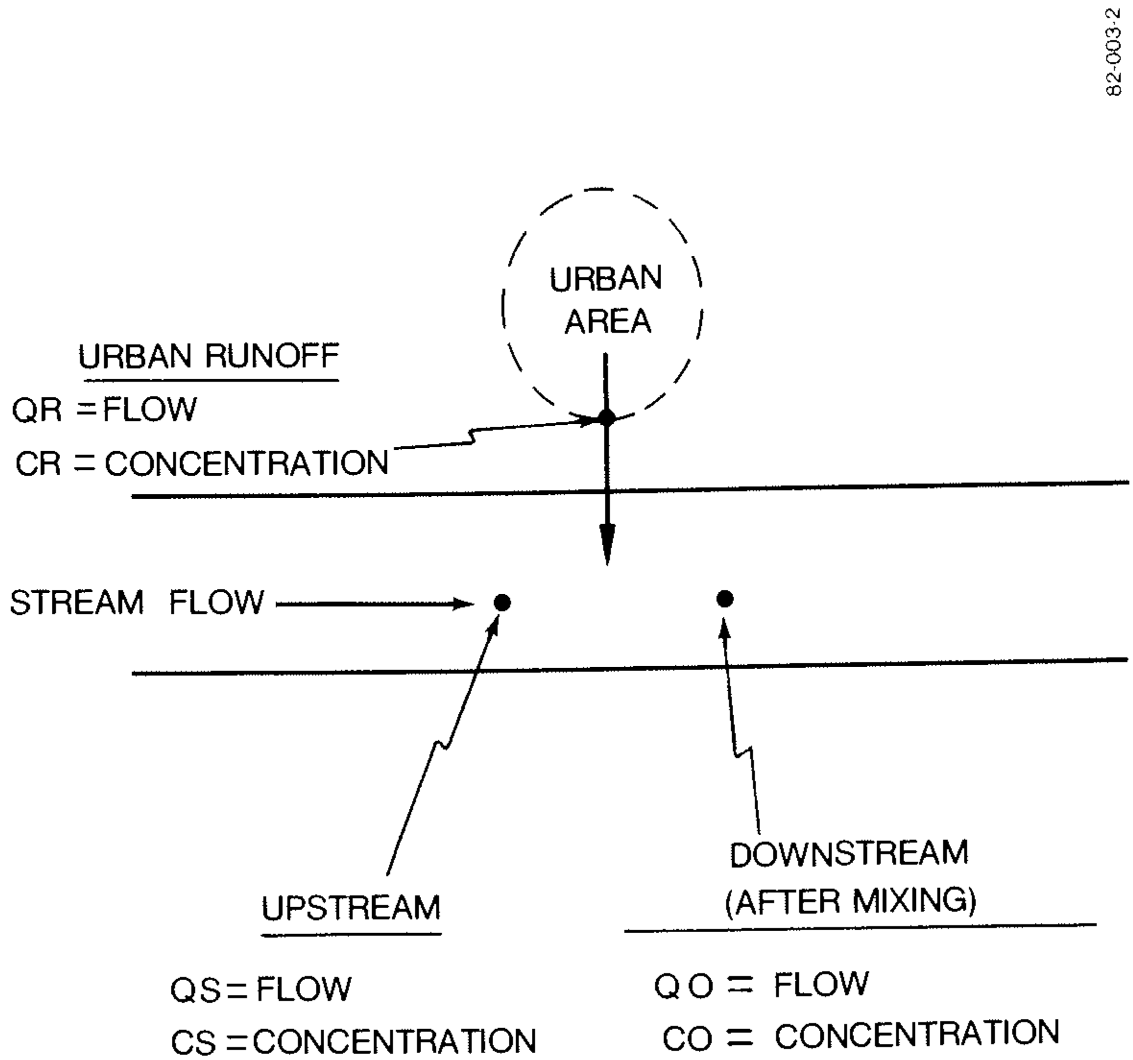


Figure 5-2. Idealized Representation of Urban Runoff Discharges Entering a Stream

stream concentration just downstream of all of the discharges as shown in Figure 5-2. The four input variables considered are:

- Urban runoff flow (QR)
- Urban runoff concentration (CR)
- Stream flow (QS)
- Stream concentration (CS)

Each is considered to be a stochastic random variable, which together combine to determine downstream flow and concentration. In addition, all variables are assumed to be independent, except urban runoff flow and streamflow where correlation effects can be incorporated as warranted.

An essential condition of the current computational structure is that each of the four variables which contribute to downstream receiving water quality can be adequately represented by a lognormal probability distribution; from analysis of data or other estimating procedures, the statistical properties of each of the input parameter distributions are defined. Examination of a reasonably broad cross-section of data indicates that lognormal probability distributions can adequately represent discharges from the rainfall/runoff process, the concentration of contaminants in the discharge, and the daily flow record of many rivers and streams, particularly for a national scale screening approach. It should be noted, however, that modifications of the computation techniques could be made to accommodate the use of other distributions (e.g., gamma, exponential) for some or all of the parameters.

The analysis procedure is described in more detail in the supplementary NURP report cited earlier. It essentially operates as follows:

- Downstream Concentrations. Stream concentrations of a pollutant are considered to result from the combination of upstream flow at background concentration and runoff flow at its concentration. Variations in stream concentrations below the urban runoff discharge result from variations in each of these inputs; the most significant source of variation being whether or not an event is occurring (i.e., whether runoff flows and loads are present). Stream flows must be considered because of the major effect of dilution on the resulting concentrations. Upstream concentrations can, however, be set at zero for the calculations; in which case, the result obtained is the exclusive effect of urban runoff discharges, and not the overall expected stream concentration. Effects of urban runoff can be evaluated by considering only the periods during which runoff occurs.

- Parameter Estimates. Estimates for runoff flows and concentrations are developed from information derived from the NURP monitoring programs. Information on stream flow can be obtained from analysis of local stream gage records. Upstream concentrations tend to be very site-specific; for this reason, the screening analysis calculated only the effect of urban runoff discharges.

- Statistical Calculations. From the statistical properties (specifically, the means and standard deviations) of the flows and concentrations, properties of the dilution ratio can be defined, and the statistical properties of the resulting in-stream concentrations are calculated directly. The frequency with which any particular target concentration is exceeded during wet weather can be calculated from the statistical properties of stream concentration, using formulas or scaled directly from a standard plot of cumulative (lognormal) probability distributions.

  The frequency with which the target concentration is exceeded during all periods -- wet and dry -- is simply the product of the wet weather frequency and the probability (frequency) that it is raining. The probability that it is raining at any time is defined by the ratio of mean storm duration to mean inter-storm period, derived from the rainfall statistics.

$$\frac{D = \text{mean duration of storms}}{\Delta = \text{mean interval between storm midpoints}} = \text{fraction of time it is wet}$$

- Mean Recurrence Interval. In the presentation of results in Chapter 7, the probability distribution of event mean stream concentrations of an urban runoff pollutant during runoff periods is converted to a Mean Recurrence Interval (MRI) as a device to assist in the interpretation of results. The recurrence interval is defined as the reciprocal of probability. Because the basic calculation is based on storm events, this definition yields the overall average number of storms between specific event occurrences. Event recurrence is converted to what is believed to be a more meaningful time recurrence by dividing by the average number of storms per year, which is developed from analysis of rainfall records and defined as

  $$\frac{\text{Hours/year} = 8760}{\text{Average interval between storm midpoints}} = \text{average \# storms per year}$$

  As an example of the MRI calculations consider a stream concentration which has an exceedance probability of 1.0 percent (Pr = 0.01)

  $$\text{Recurrence Interval} = 1/\text{Pr} = 1/0.01 = 100$$

  The analysis is in terms of storm events, not time. Therefore this result is interpreted as one storm in every 100 events on average, will produce concentrations greater than the selected value. For an area where rainfall patterns produce an average of 100 storms per year, the average recurrence interval expressed in time units rather than events, is:

  $$\begin{array}{l}\text{Recurrence}\\ \text{Interval}\\ \text{(time)}\end{array} = \frac{\text{event recurrence}}{\text{\# events/year}} = \frac{100 \text{ events}}{100 \text{ events/year}} = 1 \text{ year}$$

Currently, the primary use of the above procedure is as a screening tool in which approximate results and relative values are of interest. In this regard, NURP believes the Mean Recurrence Interval is a very useful definition. It should be interpreted as the long-term average interval between occurrences.

When results of this nature are interpreted, the following factors should be noted. The recurrence intervals of most interest relate to very low probabilities of occurrence. The tails of distributions may have appreciable uncertainty, and in the natural water systems, distributions may be lognormal over the bulk of the range but may deviate from the assigned distribution at the extremes. Computed stream concentrations at long recurrence intervals are likely to be conservative, that is, overstated because there are likely to be practical upper limits for runoff concentrations and lower limits to stream flow.

It also should be noted that serial correlations of streamflows or the tendency of wet and dry years to occur in clusters, though not a general behavior, may be significant in some cases. This situation would cause the average one year condition, for example, not to repeat itself every year but rather to occur several times per year, at intervals greater than one year.

Other Receiving Waters

Other receiving waters of general interest in assessing urban runoff effects include lakes, estuaries, embayments, and coastal zones. The methods adopted for lakes are briefly described below. The other receiving waters generally require site-specific and often complex analysis techniques (numerical methods, multi-dimensional modeling, etc.). Given this, a generalized screening-level assessment was not believed to be appropriate for this report. A number of the individual NURP projects consider these coastal water bodies and report on the specific methods adopted and results obtained.

For lake eutrophication problems, the time scale for analysis is considerably longer than the short (event scale) periods necessary for estuaries and rivers. For this case, annual average loads were used in a steady-state analysis performed using the type of empirical model advanced by Vollenweider and others. The EMC data developed from NURP monitoring programs can be readily converted to annual loads directly from annual flows or indirectly based on annual rainfall.

For total phosphorus, typically the limiting nutrient of concern, average concentrations are calculated using the following formula:

$$P = \frac{W'}{H/\tau \cdot \upsilon_s} \cdot 1000$$

The input values include pollutant mass loading (W'), lake physical characteristics of depth (H) and residence time ($\tau$) and reaction rate coefficients ($\upsilon_s$). The relative contribution of all load sources to lake total P concentrations can be defined by solving this equation for each of the sources. By comparing results in terms of lake concentrations for initial conditions (no control), and then modifying loads to reflect various levels of control, alternative control operations can be compared directly to effect on lake water quality.

Some judgement is involved in defining acceptable lake water quality concentrations, which depend in part on water use and on regional norms and expectations.

## EVALUATION OF CONTROLS

### General

The evaluation of controls has two elements: (a) characterizing the controls' performance capabilities and (b) defining costs. For this report, only the characterization of performance is emphasized; cost relationships are addressed to a more limited extent. EPA's Economic Analyses Staff, Office of Analysis and Evaluation, has prepared the following report under contract:

> "Collection of Economic Data from Nationwide Urban Runoff Program Projects," EPA Office of Water Regulations and Standards, April 7, 1982.

This report, issued at an early stage in the NURP program, assembled and analyzed cost information on potential control measures. Useful cost information for detention basins was developed by the Washington, D.C. area NURP project and is discussed further in Chapter 8.

### Detention Basins

There are a number of procedures which can be adopted for evaluation of detention basin control devices. Procedures adopted by individual NURP projects are described in project reports. The procedure adopted by NURP to generalize the analysis of detention basins, and provide a planning level basis for estimating capabilities and requirements, is detailed in a detention basin handbook being issued by NURP as a supplementary report.

Results presented in Chapter 8 provide a summary of observed performance characteristics of the detention devices monitored under the NURP program and a projection of long-term performance expected on the basis of basin size and regional rainfall characteristics. The latter result is based on the probabalistic analysis methodology described in the supplementary report. Planning level cost estimates for control of urban runoff using this technique are also presented.

### Street Sweeping

A number of the individual NURP projects adopted street sweeping as a principal subject of investigation. Procedures and results are described in individual project reports and are consolidated and summarized in Chapter 8. The adopted procedure and detailed results are presented in the supplementary NURP report, which was cited earlier.

### Recharge Devices

Recharge devices include impoundments or other structures such as pits, trenches, retention basins, percolating catch basins, in-line percolation chambers or perforated pipes, which function by intercepting some portion of storm runoff and allowing it to percolate into the ground.

One of the basic questions which arises when controls of this type are considered is whether the percolation encouraged will produce undesirable degradation of groundwater quality. This aspect was examined by two NURP projects, and is discussed in Chapter 7 of this report.

Evaluation of percolating basins of any size is readily accomplished using the standard storage/treatment routines of stormwater models such as STORM or SWMM. In such cases the local soil permeability (the percolation rate) is applied as the treatment rate. In addition, statistical analysis procedures described in "A Statistical Method for the Assessment of Urban Stormwater" (EPA 440/3-79-023, May 1979) have been developed. A probabalistic analysis methodology adapted from the latter approach has been used by NURP to provide estimates of performance capabilities of recharge devices, which are presented in Chapter 8. A detailed discussion of the methodology is provided in the supplementary NURP report on detention/recharge devices cited earlier.

# CHAPTER 6
# CHARACTERISTICS OF URBAN RUNOFF

## INTRODUCTION

This chapter presents a condensed summary of data developed by the individual NURP projects together with analysis results and interpretations based on the aggregated data from all projects.

Both the format for the summaries and the evaluations performed were selected to best serve the NURP objective of developing a national perspective. The results presented do not exhaust the useful information and insights which can be derived from the extensive data base that has been assembled. Individual project reports and a substantial number of articles published in a variety of technical journals independently examine specific aspects of urban runoff, often from the perspective of local issues.

Comprehensive tabulations of NURP data have been assembled and will be made available to interested parties for use in local planning or continuing research or engineering activities. As noted below, only a portion of the entire data base generated by the 28 NURP projects has been made generally accessible at this time. Under an ongoing effort, the entire data base is being subjected to final quality assurance checks and placed into a separate file, copies of which will be made available to interested parties upon request. In addition, a summary of the event averaged data, used for the analyses presented in this chapter, is reproduced in a Data Appendix issued with this report.

Field monitoring was conducted to characterize urban runoff flows and pollutant concentrations and mass loadings. This was done for a variety of pollutants at a substantial number of sites distributed throughout the country. The resultant data represent a cross-section of regional climatology, land use types, slopes, and soil conditions and thereby provide a basis for identifying patterns of similarities or differences and testing for their significance. To meet the objective of maximizing the degree of transferability of urban runoff data, the NURP approach involved covering a spectrum of regional and land use characteristics, requiring consistent quality assurance programs among all projects, and encouraging each of the projects to obtain data for a statistically significant number of storm events at a site.

The portion of the NURP data base used in the characterization of urban runoff presented in this section excludes monitoring sites which are downstream of devices which modify runoff (e.g., detention basins). The data base of acceptable "loading sites" consists of 81 sites in 22 different cities, and includes more than 2300 separate storm events. The actual number of events for specific pollutants varies, and is somewhat smaller than the total number of storms monitored because all pollutants were not measured for all storms at all sites.

Data summaries and analyses were performed using storm event average values; within-event fluctuations are not considered. An event mean concentration (EMC) for pollutants of interest has been determined for each monitored storm. Preliminary results presented in an earlier NURP report were based on analysis of "pooled" EMCs which were available at the time regardless of site. This provided a useful start, a reference for individual NURP project activities, and established the order of magnitude of concentrations of various pollutants in urban runoff. With the substantially larger data set now available, a more useful approach is possible. For the analyses and comparisons presented in this chapter, the storm event average data were aggregated by site to describe site characteristics. Site mean values were then aggregated or compared.

Summaries, comparisons, and evaluations were restricted to concentrations and runoff-rainfall ratios. Although loading data (Kg/Ha) are also available for all monitored storms, they have not been used in comparisons for the following reason. Mass load is very strongly influenced by the size (volume) of the monitored storm event. Monitored events usually represent a very small sample of all storms for an area, are generally biased toward larger events, and are different from site to site. Therefore comparisons between sites or locations using loading data derived from monitored storms are quite likely to present a distorted picture.

Event mean concentrations, on the other hand, have been determined to be essentially uncorrelated with runoff volume, as discussed further later in this chapter. Site comparisons can be made with high confidence levels using concentration data, and the most meaningful load comparisons would be those developed by using concentrations, area rainfall volumes, and runoff-rainfall relationships.

Separate summaries of results are provided below for standard pollutants, coliform bacteria, pollutant loads, and priority pollutants.

## LOGNORMALITY

As was pointed out in Chapter 5, the key to the mathematical tractability of the NURP methodologies is that the data can be well represented by a known probability density function (pdf). There are actually two issues involved; (1) the adequacy of the assumed pdf in terms of representing the essential characteristics of the data set in question, and (2) the estimation of the parameters of the population pdf that the observed data set is presumed to represent. These will be discussed in turn.

### Adequacy of Representation

One can fit a polynomial of order (n-1) exactly to any data set of n numerical items, but its utility in predicting the probability of realizing a given value on a subsequent trial (either within or outside the original data set, i.e., the interpolation or extrapolation problem) is likely to be very limited. The number of parameters involved and the need to investigate its properties on an individual basis are further deterrents to such a practice. There is no dearth of pdf's that have been the subject of intensive investigation. However, the selection of a pdf is an objective choice that is best made based on professional knowledge of the processes deemed important to the desired probability model and the use to be made of it. For example, if the data are known to result from the product of many small effects, their logs will be the sum of the logs of these effects. By appeal to the central limit theorem, it is known that this sum is asymptotically normal and, therefore, that the data will be lognormally distributed. Based upon such natural expectations and prior experience (of a growing body of other workers in the field as well), the lognormal pdf was chosen. The fact that the variables of interest can assume only positive values with a finite mean and a finite nonzero lower bound (even in a standardized form) leads to the rejection of any pdf defined over the entire real domain, such as the normal distribution for instance.

There are a number of statistical procedures for evaluating the normality of a complete sample; at least nine can be found in the current literature. Some are origin and scale invariant (e.g., the Shapiro-Wilk, standard third moment, standard fourth moment, and studentized range) and thus are appropriate for testing the composite hypothesis of normality. Others require the complete specification of the null distribution (e.g., Kolmogorov-Smirnoff, Cramer-Von Mises, weighted Cramer-Von Mises, modified Kolmogorov-Smirnoff-D, and chi-squared), and typically, the mean and variance of the specified normal hypothesis are taken to be the known mean and variance of the complete sample. Some procedures (e.g., chi-squared) utilize the specified theoretical pdf, while others (e.g., the modified Kolmogorov-Smirnoff D-test) utilize the cumulative frequency distribution.

In testing for normality (in the logorithmic domain in our case), one specifies the level of significance ($\alpha$), i.e., the probability of rejecting the null hypothesis when it is in fact true (Type I error). The choice of $\alpha$ requires tempered judgement, however. The power of a test ($\beta$) is the probability of rejecting the null hypothesis when it is in fact false. The probability of accepting the null hypothesis when it is in fact false (Type II error) is $1-\beta$. For a given sample size and test, fixing a value for $\alpha$ also determines a value for $\beta$ (i.e., they are not independent). The smaller the $\alpha$ level, the less powerful the test. Thus one is forced to make a trade-off between the consequences of a Type I or II error when selecting an $\alpha$ value.

The median EMC values for each constituent at each site were calculated, and these sample sets were examined for lognormality using the Kolmogorov-Smirnoff D test. The $\alpha$ levels for TSS, Total P, TKN, Total Pb, and Total Zn were all greater than 0.15, indicating a high power level. In other words, these sample sets are extremely well represented by a lognormal distribution. For COD and nitrate + nitrite the $\alpha$ levels were 0.059 and 0.057 respectively, indicating a lower power level but suggesting that even for these constituents the lognormal distribution quite well describes the data. Because BOD, Soluble P, and Total Cu were measured at fewer than half of the project sites, the D-test could not meaningfully be used (i.e., n is too small). Stated another way, at the $\alpha = 0.05$ level, the hypothesis that the samples were drawn from a population with a lognormal distribution cannot be rejected for any of the constituents examined.

Turning to the individual sites, there were very few instances where n was large enough to support the meaningful use of the D-test, and so a different approach for examining the appropriateness of the lognormal distribution was used. Essentially it consisted of examining the cumulative frequency distributions (in log space) and third and fourth moment based statistics for adequacy of representation. Taking into account detection limit phenomenon, uncertainties associated with sampling and analytical determination errors (especially at low concentration levels), and an occasional outlier, well over 90 percent of the constituent distribution at all NURP sites were quite well represented by the lognormal distribution. For the few remaining data sets, the lognormal distribution, although not perfect, was adequate for our purposes.

Estimation of Parameters

As noted in Chapter 5, the lognormal distribution is completely specified by two parameters, the mean and the coefficient of variation. The values of these two parameters as calculated from the sample data set are the best estimates of the parameters of the underlying population in the maximum likelihood sense. For this reason, they were used in the NURP analysis. However, due to the existence of detection limit problems and sampling/analytical determination errors, the reasonableness of this decision was examined in general for all constituents and in great detail for Total Cu, the results of which will be described below.

For each of the 49 NURP sites where at least five Total Cu determinations were made, data were plotted (in logarithmic form) on probability paper. A line of best fit was drawn in, using professional judgement where detection limit or outlier problems existed, and the values of the median and standard deviation were read from the plot and converted into arithmetic space. These were then compared with those values calculated from the data themselves. One example is given in Figure 6-1 (the 116th and Claude Street site in Denver). Here the median and coefficient of variation from the plot (20 µg/l and 0.75) compare very well with those calculated directly from the data (22 µg/l and 0.74).

An example of an outlier plot is given in Figure 6-2 (the strip commercial site in Knoxville, TN). The one very low value (1 µg/l) is one-twentieth the typical detection limit (20 µg/l) and clearly does not belong to the same distribution that the other values do. Ignoring it, a very good fit exists and the parameters of the plot are 30 µg/l and 0.37 for the median and coefficient of variation as compared with the 25 µg/l and 1.35 values calculated from the data. The difference in medians is not too great, but the difference in coefficients of variation is quite large (over a factor of 3.5). This means that the upper end of the tail of the pdf is quite overestimated by the parameters estimated from the data and, consequently, that

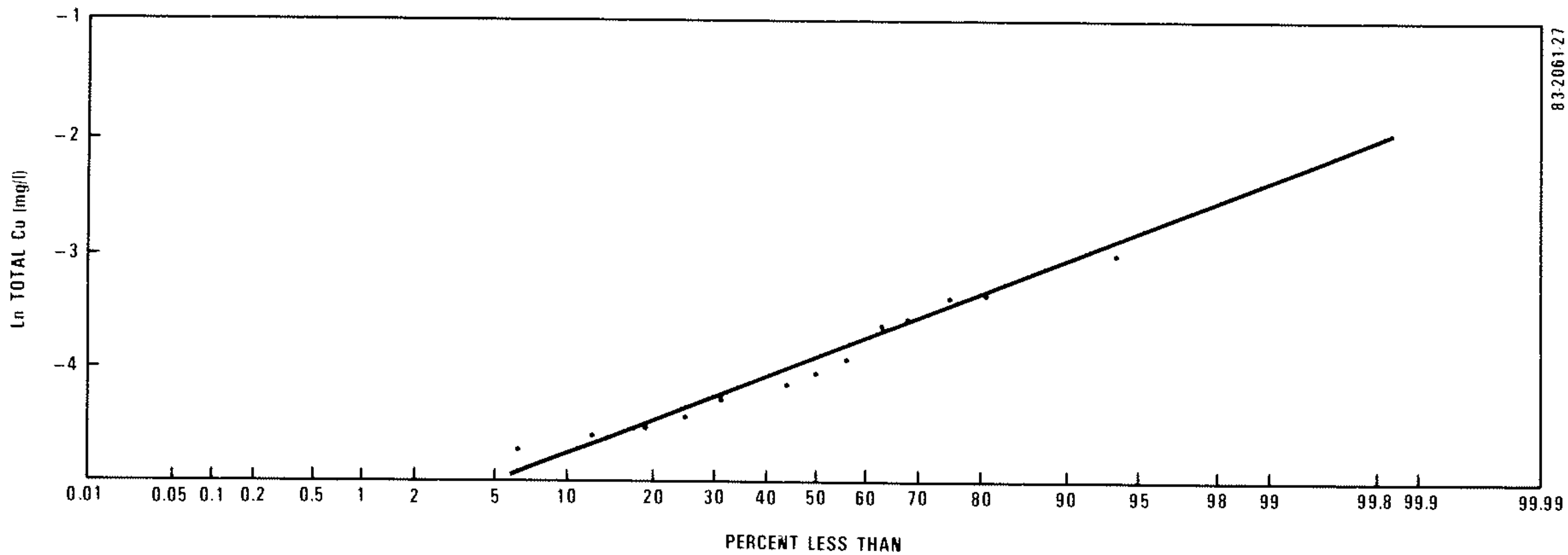


Figure 6-1. Cumulative Probability Distribution of Total Cu at C01 116 and Claude Site

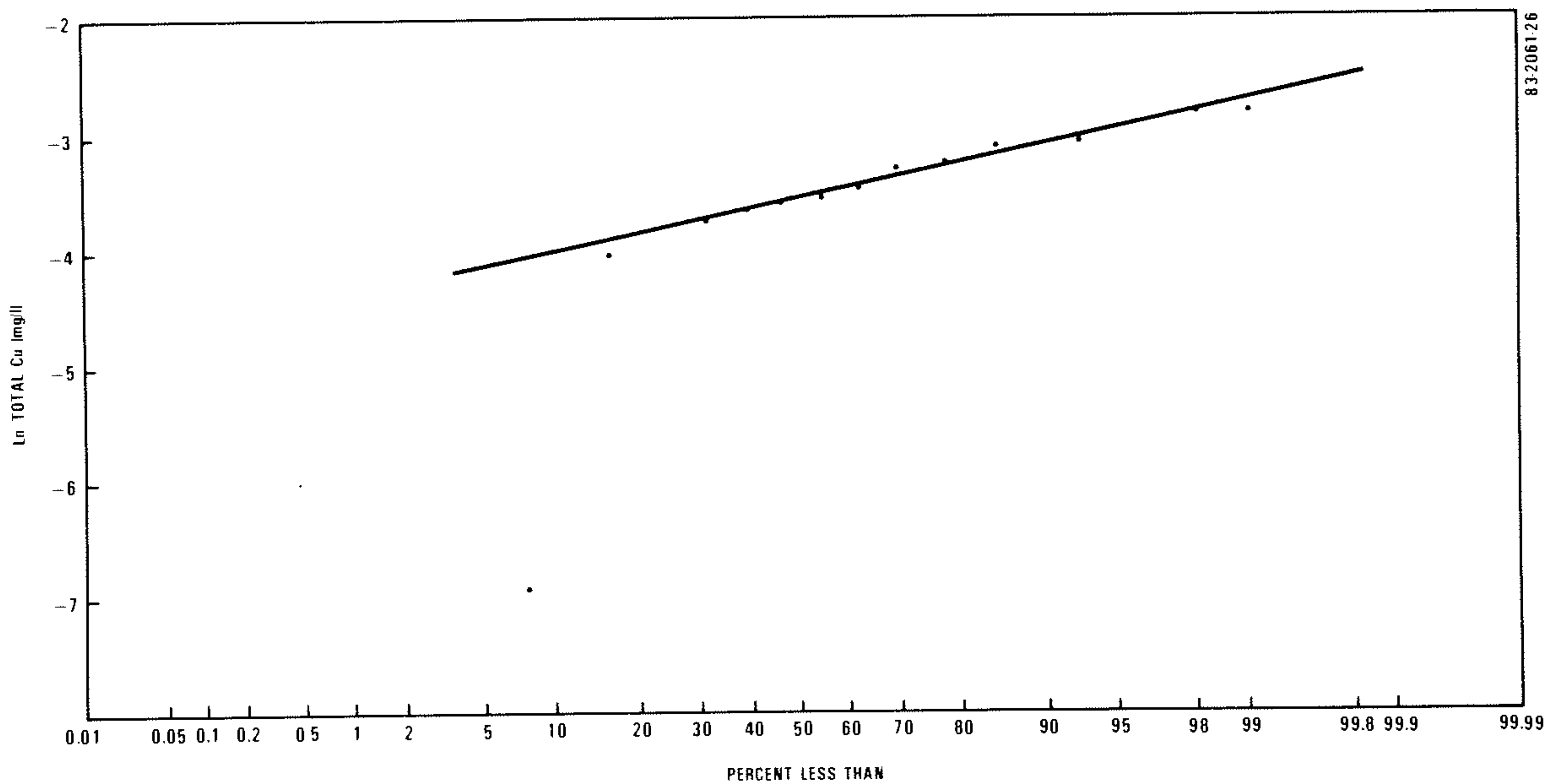


Figure 6-2. Cumulative Probability Distribution of Total Cu at TN1 SC Site

subsequent analyses will be extremely conservative, i.e., higher values of copper concentrations will occur less often than predicted. In general, the effect of an outlier is to increase or decrease the estimate of the median, depending upon whether the outlier is high or low, and to increase the estimate of the coefficient of variation as compared to those obtained from the remainder of the data.

An example of a detection limit problem is given in Figure 6-3, the plot of copper data of the Durham, NH parking lot site. Although only four points appear on the plot, actually n = 31, meaning that 27 points are represented by the first plotting position (90.6 percent). These values (all reported at 100 μg/l) are presumably the detection limit of the analytical laboratory. Of course in reality not all 27 values are 100 μg/l; they are simply equal to or less than this value. Fitting a line to the remaining four data points merely assigns appropriate plotting positions to these "less than" values. The estimates of the median and coefficient of variation from the plot are 63 μg/l and 0.36 respectively, as compared to the estimates from the data of 103 μg/l and 0.13. In this case, the latter significantly overestimates the median and significantly underestimates the coefficient of variation, and this is the general effect when a detection limit problem is present. In terms of the effect on prediction of rare occurrences of high copper levels (the upper tail of the pdf) these effects are somewhat counterbalancing. To the extent that the increase in the coefficient of variation dominates, the results of subsequent analyses will not be conservative, since larger concentrations will occur somewhat more frequently than would be predicted.

When the results of this exercise are compared for all 49 sites, the median as estimated from the plot was found to be higher than that estimated from all the data at only six sites, was equal at five sites, and was less at 38 sites. However, at only three sites was the change greater than 10 μg/l. Considering the population of all copper sites, the average median is 47 μg/l and the coefficient of variation is 0.84 when the estimates are based on all the data. If the estimates are based upon the plots, the respective values are 42 μg/l and 0.24 respectively. The significant reduction in the coefficient of variation in this latter case deserves comment, because it suggests that much of the apparent variability from site to site is due to data artifacts such as detection limit phenomena, outliers, and/or sampling/analytical errors. Similar comparisons of the coefficients of variation for each site showed increases at 21 sites, 6 unchanged, and decreases at 22 sites. Considering all sites, the average coefficient of variation is essentially unchanged (0.61 vs 0.63) as is its variability (0.47 vs 0.49).

Based on the results of the analyses which have been performed, the NURP findings are as follows:

- Lognormal distributions adequately represent both the storm-to-storm variations in pollutant EMC's at an urban site, and site-to-site variations in the median EMC's which characterize individual sites.

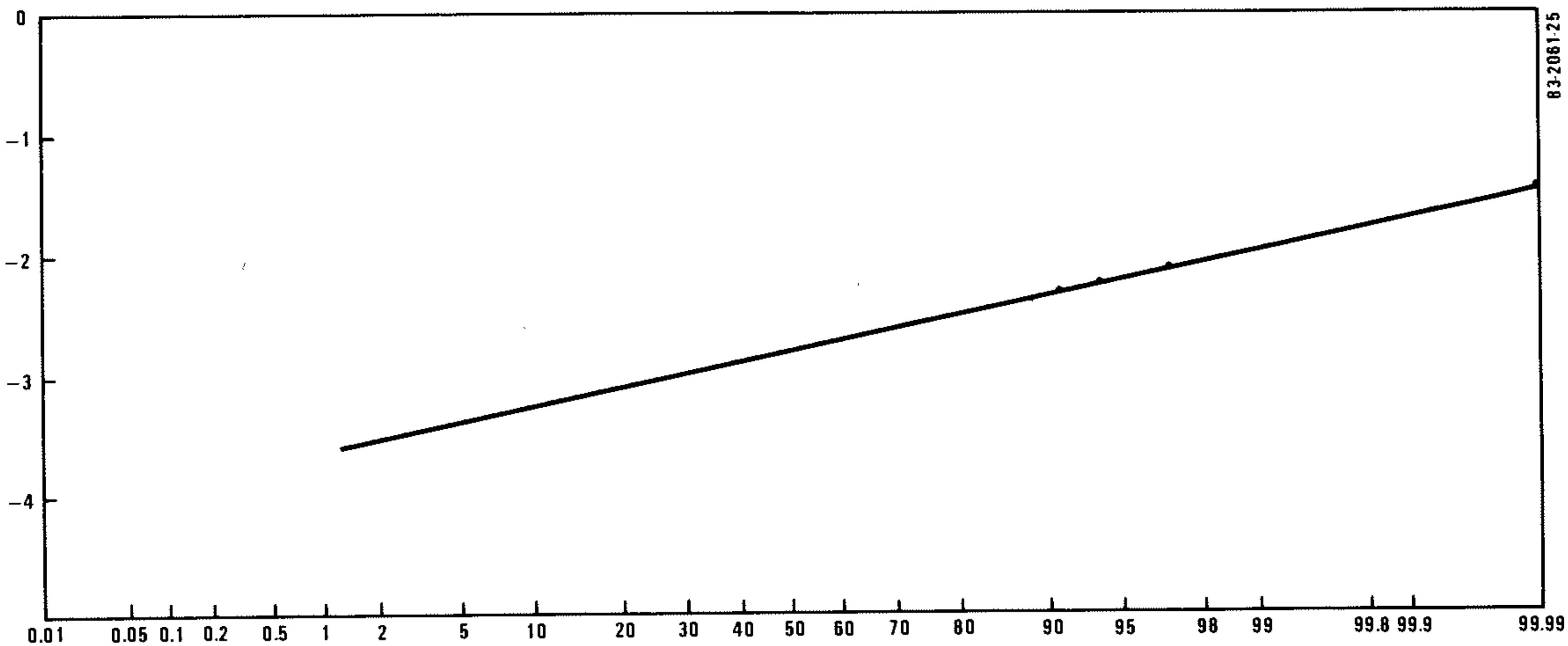


Figure 6-3. Cumulative Probability Distribution of Total Cu at NH1 Pkg. Site

- More detailed analysis to compensate for sampling errors (e.g., outliers and detection limit problems) would result in some adjustments in the statistical parameters tabulated later on in this chapter. The data summaries presented are based on statistics computed directly from the log transforms of the data.

- Such adjustments would not have any significant effect on overall results nor on the general conclusions reached. However, at a small percentage of sites, the parameter estimates for some pollutants would change significantly.

- In general, estimates of the site median EMC would be least affected; estimates of variability more so. It is likely that the very high or very low values for coefficient of variation (storm-to-storm variability) would be adjusted to more central values.

STANDARD POLLUTANTS

This grouping includes the following pollutants:

TSS - Total Suspended Solids
BOD - Biochemical Oxygen Demand
COD - Chemical Oxygen Demand
TP - Total Phosphorus (as P)
SP - Soluble Phosphorus (as P)
TKN - Total Kjeldahl Nitrogen (as N)
$NO_{2+3}$-N - Nitrite + Nitrate (as N)
Cu - Total Copper
Pb - Total Lead
Zn - Total Zinc

It includes pollutants of general interest which are usually examined in other studies (both point and nonpoint sources) and includes representatives of important categories of pollutants, namely solids, oxygen consuming constituents, nutrients, and heavy metals.

Condensed Data Summary

Tables 6-1 through 6-10 summarize the NURP results for these pollutants. Monitoring sites are grouped in each of the tables according to dominant land use. Broad categories have been used; residential, commercial, industrial, urban open/nonurban (other), and mixed, this latter category being used for sites which had no predominant land use. It should be noted that the industrial category does not include heavy industry sites, but more typically reflects an industrial park type of use. As a result, most of these sites are more closely related to a commercial use than to the typical image called up by the term industrial site. For subsequent comparisons, the data shown in Tables 6-1 through 6-10 for the commercial and industrial sites, are combined and designated as commercial land use.

# TABLE 6-1. SITE MEAN TSS EMCs (mg/ℓ)

Residential

| | Site | Land Use % | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | TSS Mean | TSS COV | TSS Median | TSS 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CO1 Big Dry Cr | 100 | 11 | 19 | 41 | 14 | 333 | 1.04 | 265 | 182-385 |
| 2 | CO1 Cherry | 100 | 57 | 24 | 18 | 14 | 160 | .98 | 129 | 87-190 |
| 3 | CO1 116 & Lamar | 100 | 167 | 14 | 29 | 16 | 365 | 1.17 | 232 | 154-349 |
| 4 | DC1 Duffer | 100 | 12 | - | - | 8 | 46 | 1.02 | 39 | 51-74 |
| 5 | DC1 Carriage | 100 | 68 | 21 | 37 | 49 | 175 | 1.47 | 98 | 76-127 |
| 6 | DC1 Stratton | 100 | 8 | - | - | 31 | 54 | 1.01 | 38 | 30-49 |
| 7 | IL1 John N | 100 | 54 | 18 | 19 | 51 | 215 | 1.36 | 127 | 96-155 |
| 8 | KS1 Overton | 100 | 58 | 8 | 38 | 15 | 2216 | 1.42 | 1243 | 166-2037 |
| 9 | MA2 Healoti | 100 | 59 | 5 | 18 | 5 | 78 | 2.49 | 29 | 8-111 |
| 10 | MD1 Baltimore Hill | 100 | 14 | 10 | 51 | 19 | 74 | 1.32 | 45 | 30-68 |
| 11 | MD1 Homeland | 100 | 23 | 9 | 29 | 13 | 50 | 1.05 | 26 | 15-46 |
| 12 | MD1 Mt Wash | 100 | 17 | 12 | 29 | 20 | 96 | 1.12 | 62 | 44-89 |
| 13 | MD1 Res Hill | 100 | 10 | 35 | 76 | 13 | 123 | 1.05 | 85 | 57-135 |
| 14 | NY1 Carll's R. | 100 | 71 | 13 | 20 | 23 | 42 | .85 | 32 | 25-47 |
| 15 | NI1 Unque | 100 | - | - | - | 9 | 65 | .53 | 57 | 41-81 |
| 16 | NI1 Brandon | 100 | 160 | 5 | 22 | 10 | 114 | 1.15 | 98 | 57-150 |
| 17 | NI2 E. Roch. | 100 | 346 | 18 | 19 | 7 | 294 | 1.12 | 198 | 101-380 |
| 18 | TX1 Rollingwood | 100 | 60 | 3 | 21 | 9 | 227 | 1.13 | 150 | 85-761 |
| 19 | WA1 Surrey | 100 | 95 | 9 | 29 | 117 | 111 | .51 | 101 | 94-108 |
| 20 | WI1 Burbank | 100 | 61 | 15 | 50 | 45 | 266 | .44 | 297 | 219-370 |
| 21 | WI1 Hastings | 100 | 13 | 17 | 51 | 35 | 170 | .68 | 141 | 117-169 |
| 22 | FL1 Rhyne Apts | 100 | 9 | - | 6 | 17 | 51 | 1.23 | 34 | 21-56 |
| 23 | TX1 Hart | 99 | 378 | 9 | 40 | 35 | 155 | 1.51 | 82 | 49-137 |
| 24 | WI1 Lincoln | 97 | 36 | 18 | 57 | 23 | 251 | .89 | 206 | 165-258 |
| 25 | TN1 R2 | 96 | 29 | 4 | 13 | 11 | 61 | 1.13 | 42 | 25-68 |
| 26 | DC1 Westleigh | 93 | 41 | 7 | 21 | 41 | 75 | 1.45 | 43 | 33-57 |
| 27 | KS1 IC - 92nd | 92 | 63 | - | 37 | 11 | 156 | .84 | 119 | 83-171 |
| 28 | IL1 John S. | 93 | 39 | 19 | 18 | 49 | 248 | 1.50 | 176 | 106-178 |
| 29 | IN1 F1 | 91 | 159 | 11 | 33 | 11 | 611 | .72 | 492 | 345-704 |
| 30 | WA1 Lake Hills | 91 | 102 | 12 | 37 | 126 | 127 | .80 | 100 | 90-110 |
| 31 | IL1 Maltby S. | 90 | 28 | 22 | 13 | 59 | 111 | 1.08 | 213 | 174-256 |
| 32 | FL1 Charter Hdq | 99 | 42 | - | 16 | 12 | 31 | 1.76 | 10 | 9-10 |
| 33 | DC1 Fairidge | 88 | 19 | - | 14 | 47 | 25 | 1.55 | 14 | 18-18 |
| 34 | CO1 Asbury | 88 | 127 | 9 | 22 | 9 | 493 | .82 | 380 | 244-593 |
| 35 | IL2 Comb Inlets | 85 | 598 | 8 | 17 | 27 | 250 | .75 | 200 | 161-249 |
| 36 | MA1 Locust | 95 | 164 | 11 | 16 | 6 | 257 | 1.75 | 128 | 48-339 |
| 37 | NC1 #3033 | 84 | 324 | 6 | 27 | 66 | 291 | 1.92 | 175 | 104-174 |
| 38 | MA1 Jordan | 79 | 110 | 10 | 21 | 9 | 79 | 1.74 | 39 | 19-81 |
| 39 | DC1 Stedwick | 78 | 27 | 15 | 34 | 47 | 54 | 1.02 | 38 | 11-47 |

Mixed

| | Site | Land Use % | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | TSS Mean | TSS COV | TSS Median | TSS 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | KS1 Noland | - | 30 | 7 | 69 | 16 | 290 | .91 | 208 | 148-292 |
| 2 | MD1 Hampden | - | 12 | 40 | 72 | 20 | 62 | 1.62 | 43 | 28-47 |
| 3 | IL1 Mayfair N | - | 17 | 2 | 58 | 58 | 281 | 1.01 | 179 | 165-239 |
| 4 | MI1 Waverly | - | 10 | 11 | 68 | 15 | 85 | 1.78 | 52 | 39-69 |
| 5 | IN1 SC | - | 187 | 0 | 95 | 12 | 71 | 1.07 | 45 | 31-74 |
| 6 | WI1 Wood Ctr | - | 45 | 12 | 51 | 47 | 363 | .78 | 282 | 255-351 |
| 7 | MA1 Rt 9 | - | 318 | 7 | 25 | 7 | 151 | 2.05 | 154 | 60-315 |
| 8 | MA1 Convent | - | 180 | 1 | 33 | 8 | 59 | 1.53 | 30 | 18-43 |
| 9 | MI1 Grand R Gt | - | 453 | 5 | 38 | 21 | 159 | 1.76 | 92 | 45-110 |
| 10 | MI1 Pitt AA-S | - | 2001 | 2 | 21 | 6 | 46 | .77 | 43 | 20-48 |
| 11 | MI7 Cedar | - | 76 | - | 5 | 27 | 293 | 1.92 | 139 | 99-202 |
| 12 | MA1 Anna | - | 601 | 9 | 12 | 6 | 150 | 2.45 | 16 | 19-166 |
| 13 | MI1 Pitt AA-H | - | 2871 | 7 | 26 | 6 | 68 | .47 | 57 | 42-65 |
| 14 | MI1 Grace N | - | 164 | 5 | 25 | 23 | 172 | .95 | 149 | 101-171 |
| 15 | MI3 Swift Run | - | 1707 | 1 | 4 | 5 | 56 | .93 | 59 | 26-124 |
| 16 | SD1 Meade | - | 2030 | - | - | 15 | 3091 | 1.39 | 1804 | 1126-2897 |
| 17 | CA1 Knox | - | 1542 | 12 | - | 16 | 283 | 1.12 | 111 | 115-255 |
| 18 | FL1 N. Jesuit | - | 30 | - | 13 | 15 | 87 | 1.99 | 23 | 11-49 |
| 19 | FL1 Wilder | - | 194 | - | 97 | 19 | 43 | .71 | 27 | 20-37 |
| 20 | CO1 North Ave | - | 69 | 9 | 50 | 32 | 492 | .96 | 354 | 278-451 |

Commercial

| | Site | Land Use % Coml | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | TSS Mean | TSS COV | TSS Median | TSS 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CO1 Villa Italia | 100 | 74 | 0 | 91 | 27 | 260 | 1.89 | 122 | 61-187 |
| 1 | NC1 1013 (CBD) | 100 | 23 | 0 | 69 | 60 | 163 | 1.15 | 117 | 68-111 |
| 3 | NI3 Southgate | 100 | 179 | 2 | 21 | 12 | 141 | .76 | 112 | 79-150 |
| 4 | WI1 Post Office | 100 | 12 | 0 | 100 | 56 | 212 | .90 | 161 | 131-197 |
| 5 | NH1 Pkg Lot | 100 | 1 | 0 | 91 | 12 | 74 | 1.68 | 18 | 27-54 |
| 6 | IN1 CBD | 100 | 26 | 0 | 09 | 15 | 121 | .73 | 99 | 74-133 |
| 7 | WI1 Rustler | 100 | 12 | 0 | 100 | 42 | 202 | .68 | 167 | 142-196 |
| 8 | KS1 IC Metcalf | 96 | 58 | - | 97 | 32 | 80 | 2.12 | 34 | 21-55 |
| 9 | FL1 Norma Pk | 91 | 47 | - | 85 | 17 | 22 | 1.13 | 14 | 9-22 |
| 10 | WI3 State Fair | 74 | 29 | 10 | 77 | 29 | 412 | .97 | 296 | 279-362 |

Urban Open and Nonurban

| | Site | Land Use % Open | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | TSS Mean | TSS COV | TSS Median | TSS 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CA1 Seaview | 100 | 632 | - | - | 11 | 738 | .63 | 551 | 185-188 |
| 2 | CO1 Rooney Gulch | 100 | 405 | 0 | 3 | 7 | 411 | .60 | 341 | 223-921 |
| 3 | NY2 Zmarnell | 100 | 28,416 | - | 4 | 11 | 154 | .92 | 111 | 74-113 |
| 4 | NY2 English Br | 98 | 5,748 | - | 1 | 29 | 17 | 2.45 | 6 | 4-10 |
| 5 | NI2 West Br | 97 | 6,338 | - | 1 | 28 | 64 | 2.77 | 22 | 14-35 |
| 6 | NY3 Ingnas Lr | 91 | 17,728 | 1 | 11 | 9 | 63 | .74 | 51 | 14-77 |
| 7 | MI5 Traver Cr | 96 | 2,103 | - | 6 | 5 | 13 | .17 | 26 | 14-50 |
| 8 | NY2 Sheriff Oaci | 80 | 562 | - | 7 | 32 | 178 | 2.35 | 149 | 09-224 |

Industrial

| | Site | Land Use % | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | TSS Mean | TSS COV | TSS Median | TSS 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | MA2 Addison | 100 | 19 | 0 | 69 | 5 | 43 | .81 | 11 | 14-73 |
| 2 | MI1 Indus Drain | 100 | 63 | 0 | 64 | 18 | 92 | .87 | 71 | 53-95 |
| 1 | KS1 Lenexa | 56 | 72 | - | 44 | 18 | 102 | 1.33 | 63 | 40-92 |
| 4 | MI1 Grace S. | 52 | 15 | 5 | 19 | 20 | 188 | .94 | 137 | 101-186 |

# TABLE 6-2. SITE MEAN BOD EMCs (mg/ℓ)

**Residential**

| | Site | Land Use % | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | BOD Mean | BOD COV | BOD Median | BOD 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CO1 Big Dry Cr | 100 | 31 | 19 | 41 | 0 | - | - | - | - |
| 2 | CO1 Cherry | 100 | 57 | 24 | 38 | 0 | - | - | - | - |
| 3 | CO1 1162Clayde | 100 | 167 | 14 | 24 | 0 | - | - | - | - |
| 4 | DC2 Dufief | 100 | 12 | - | - | 0 | - | - | - | - |
| 5 | DC1 Lakeridge | 100 | 68 | 21 | 33 | 0 | - | - | - | - |
| 6 | DC1 Stratton | 100 | 8 | - | - | 4 | - | - | - | - |
| 7 | IL1 John N | 100 | 54 | 18 | 19 | 0 | - | - | - | - |
| 8 | KS1 Overton | 100 | 58 | 8 | 38 | 5 | 12 | .59 | 11 | 6-18 |
| 9 | MA2 Hemlock | 100 | 50 | 5 | 16 | 0 | - | - | - | - |
| 10 | MD1 Bolton Hill | 100 | 14 | 10 | 51 | 0 | - | - | - | - |
| 11 | MD1 Mooeland | 100 | 23 | 9 | 29 | 0 | - | - | - | - |
| 12 | MD1 Mt Wash | 100 | 17 | 12 | 29 | 0 | - | - | - | - |
| 13 | MN1 Rec Hill | 100 | 10 | 55 | 76 | 0 | - | - | - | - |
| 14 | NH1 Cahill's P. | 100 | 11 | 13 | 20 | 0 | - | - | - | - |
| 15 | NY1 Unqua | 100 | - | - | - | 0 | - | - | - | - |
| 16 | NY3 Cranston | 100 | 106 | 5 | 22 | 0 | - | - | - | - |
| 17 | NY1 E. Rock. | 100 | 148 | 18 | 38 | 0 | - | - | - | - |
| 18 | TX1 Rollingwood | 100 | 60 | 3 | 21 | 0 | - | - | - | - |
| 19 | WA1 Surrey | 100 | 95 | 9 | 29 | 0 | - | - | - | - |
| 20 | WI1 Burbank | 100 | 61 | 15 | 50 | 28 | 1 | .64 | 6 | 5-1 |
| 21 | WI1 Hastings | 100 | 19 | 12 | 51 | 20 | 9 | .62 | 8 | 6-10 |
| 22 | IL1 Young Acts | 100 | 9 | - | 6 | 12 | 16 | 1.10 | 11 | 1-12 |
| 23 | TX1 Hart | 99 | 328 | 0 | 40 | 4 | - | - | - | - |
| 24 | WI1 Lincoln | 91 | 36 | 18 | 67 | 11 | 18 | 1.21 | 12 | 7-20 |
| 25 | TN1 R2 | 96 | 95 | 4 | 13 | 10 | 9 | .66 | 7 | 5-10 |
| 26 | DC1 Westleigh | 93 | 41 | 1 | 21 | 2 | - | - | - | - |
| 27 | KS1 IC - 92nd | 92 | 63 | - | 17 | 5 | 29 | .60 | 23 | 13-41 |
| 28 | IL1 John S. | 92 | 39 | 18 | 18 | 0 | - | - | - | - |
| 29 | TN1 R1 | 91 | 69 | 13 | 13 | 9 | 14 | .87 | 11 | 7-18 |
| 30 | WA1 Lake Hills | 91 | 102 | 12 | 37 | 0 | - | - | - | - |
| 31 | IL1 Mallis S. | 90 | 19 | 12 | 37 | 0 | - | - | - | - |
| 32 | IL1 Charter Hou | 89 | 42 | - | 15 | 12 | 11 | 1.24 | 6 | 5-33 |
| 33 | DC1 Fairidge | 88 | 19 | - | 34 | 6 | 5 | .64 | 4 | 2-7 |
| 34 | CO1 Asbury | 86 | 123 | 9 | 22 | 0 | - | - | - | - |
| 35 | IL2 Comb Inlets | 85 | 524 | 6 | 17 | 0 | - | - | - | - |
| 36 | MA1 Locust | 85 | 154 | 11 | 16 | 0 | - | - | - | - |
| 37 | KS1 [illegible] | 84 | 314 | 6 | 27 | 7 | 11 | 1.13 | 10 | 6-35 |
| 38 | MD1 Jordan | 79 | 110 | 10 | 21 | 0 | - | - | - | - |
| 39 | DC1 Stedwick | 78 | 27 | 15 | 34 | 0 | - | - | - | - |

**Urban Open and Nonurban**

| | Site | Land Use % Open | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | BOD Mean | BOD COV | BOD Median | BOD 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | LA1 Seaview | 100 | 13 | - | - | 0 | - | - | - | - |
| 2 | CO1 Rooney Gulch | 100 | 405 | 0 | 1 | 0 | - | - | - | - |
| 3 | NY1 Ingornoll | 100 | 68,414 | - | 4 | 0 | - | - | - | - |
| 4 | NY2 English Br | 98 | 5,249 | - | 1 | 0 | - | - | - | - |
| 5 | NY1 West Br | 97 | 6,328 | - | 1 | 0 | - | - | - | - |
| 6 | NY3 Thomas Cr | 91 | 17,718 | 1 | 11 | 9 | - | - | - | - |
| 7 | NY3 Beaver Cr | 90 | 2,303 | - | 6 | 5 | 3 | .41 | 2 | - |
| 8 | NY2 Sheriff Duck | 81 | 552 | - | 7 | 0 | - | - | - | - |

**Mixed**

| | Site | Land Use % | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | BOD Mean | BOD COV | BOD Median | BOD 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | KS1 Noland | - | 76 | 1 | 69 | 5 | - | - | - | - |
| 2 | MD1 Hampden | - | 11 | 40 | 12 | 0 | - | - | - | - |
| 3 | IL1 Hollis N | - | 17 | 3 | 58 | 0 | - | - | - | - |
| 4 | MI1 Waverly | - | 10 | 11 | 68 | 21 | 9 | .64 | 7 | 6-9 |
| 5 | TN1 SC | - | 187 | 3 | 41 | 12 | 14 | .87 | 11 | 7-16 |
| 6 | WI1 Wood Ctr | - | 45 | 12 | 51 | 11 | 14 | .54 | 11 | 11-15 |
| 7 | MA1 Rt 9 | - | 138 | 1 | 21 | 0 | - | - | - | - |
| 8 | MA1 Chevent | - | 100 | 1 | 13 | 0 | - | - | - | - |
| 9 | MI1 Grand R Ot | - | 453 | 5 | 19 | 13 | 8 | .61 | 7 | 5-8 |
| 10 | MI3 Pitt AA-S | - | 2401 | 2 | 21 | 6 | 5 | .49 | 5 | 3-7 |
| 11 | NV2 Cedar | - | 76 | - | 5 | 0 | - | - | - | - |
| 12 | MA1 Anna | - | 601 | 9 | 12 | 0 | - | - | - | - |
| 13 | MI3 Pitt AA-N | - | 2871 | 1 | 26 | 6 | 6 | .76 | 5 | 3-9 |
| 14 | MI1 Grace N | - | 164 | 6 | 28 | 11 | 8 | .78 | 7 | 5-11 |
| 15 | MI3 Swift Run | - | 1202 | 2 | 4 | 6 | 3 | .41 | 3 | 3-4 |
| 16 | SO1 Meade | - | 2030 | - | - | 14 | 19 | .75 | 15 | 11-24 |
| 17 | CA1 Knox | - | 1542 | 13 | - | 0 | - | - | - | - |
| 18 | FL1 M. Jesult | - | 30 | - | 13 | 15 | 16 | .95 | 12 | 9-17 |
| 19 | FL1 Wilder | - | 194 | - | 97 | 15 | 15 | 1.19 | 10 | 7-14 |
| 20 | CO1 North Ave | - | 69 | 9 | 50 | 12 | - | - | - | - |

**Commercial**

| | Site | Land Use % Coml | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | BOD Mean | BOD COV | BOD Median | BOD 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CO1 Villa Italia | 100 | 74 | 0 | 93 | 9 | - | - | - | - |
| 2 | MD1 1011 (CBD) | 100 | 21 | 0 | 69 | 29 | 18 | .86 | 13 | 10-20 |
| 3 | NV1 Southgate | 100 | 179 | 2 | 21 | 0 | - | - | - | - |
| 4 | WI1 Post Office | 100 | 12 | 0 | 100 | 15 | 9 | .50 | 8 | 7-11 |
| 5 | NH1 Pkg Lot | 100 | 1 | 0 | 40 | 11 | 17 | .86 | 13 | 10-16 |
| 6 | TN1 CBD | 100 | 26 | 0 | 99 | 11 | 11 | .46 | 13 | 10-15 |
| 7 | WI1 Austler | 100 | 12 | 4 | - | 27 | 13 | .79 | 10 | 8-13 |
| 8 | KS1 IC Metcalf | 96 | 58 | - | 92 | 13 | 8 | .48 | 7 | 6-9 |
| 9 | FL1 Norma St | 91 | 47 | - | 45 | 12 | 12 | .88 | 9 | 6-11 |
| 10 | WI1 State Fair | 14 | 29 | 10 | 71 | 15 | 19 | .73 | 15 | 11-20 |

**Industrial**

| | Site | Land Use % | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | BOD Mean | BOD COV | BOD Median | BOD 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | MA1 Addison | 100 | 18 | 0 | 65 | 0 | - | - | - | - |
| 2 | MI1 Lucas Drain | 100 | 61 | 0 | 64 | 9 | 10 | .58 | 9 | 6-13 |
| 3 | KS1 Lenexa | 56 | 13 | - | 44 | 8 | 14 | .77 | 11 | 7-17 |
| 4 | MI1 Grace S. | 63 | 15 | 5 | 39 | 9 | 5 | .34 | 5 | 4-6 |

| | Site | Land Use * | Area (A) | Pop. Den (r/A) | % IMP. | No. of OBS | COD Mean | COD COV | COD Median | COD 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 101 Big Dry Cr | 100 | 33 | 19 | 41 | 16 | 129 | .72 | 105 | 19-139 |
| 2 | CO1 Cherry | 100 | 57 | 34 | 38 | 18 | 122 | .69 | 102 | 71-136 |
| 3 | CO1 Clt Claude | 100 | 163 | 14 | 24 | 15 | 137 | .14 | 103 | 16-139 |
| 4 | 1M1 Dullef | 100 | 12 | - | - | 7 | 54 | .20 | 62 | 51-74 |
| 5 | OC1 Lakeridge | 100 | 62 | 31 | 13 | 44 | 60 | .56 | 50 | 43-58 |
| 6 | UC1 Stratton | 100 | 8 | - | - | 31 | 51 | .55 | 45 | 39-53 |
| 7 | 1L1 1Mbb N | 100 | 54 | 18 | 10 | 31 | 126 | .80 | 94 | 79-122 |
| 8 | KS1 Overlub | 100 | 58 | 8 | 18 | 14 | 162 | .67 | 135 | 101-180 |
| 9 | MA2 Hemlock | 100 | 50 | 5 | 10 | 11 | - | - | - | - |
| 10 | M11 Baltimore | 100 | 14 | 10 | 51 | 19 | 219 | 1.16 | 128 | 85-193 |
| 11 | MD1 Maryland | 100 | 43 | 9 | 29 | 13 | 172 | .13 | 139 | 101-192 |
| 12 | MD1 M1 Wash | 100 | 17 | 12 | 29 | 10 | 166 | .65 | 136 | 96-170 |
| 13 | M1 Res Hill | 100 | 14 | 55 | 76 | 13 | 171 | .85 | 115 | 94-194 |
| 14 | NY1 Carll's R. | 100 | 73 | 13 | 20 | 0 | - | - | - | - |
| 15 | NY1 Mague | 100 | - | - | - | 0 | - | - | - | - |
| 16 | NY3 Pralister | 100 | 166 | 5 | 22 | 8 | 33 | .43 | 31 | 24-41 |
| 17 | NY3 E. Roch | 100 | 346 | 18 | 35 | 7 | 86 | .11 | 82 | 66-102 |
| 18 | TN1 Allingwood | 100 | 50 | 3 | 31 | 9 | 70 | .05 | 64 | 44-84 |
| 19 | WA1 Shirley | 100 | 95 | 9 | 34 | 118 | 46 | .54 | 42 | 39-46 |
| 20 | WI1 Burbank | 100 | 53 | 15 | 50 | 27 | 39 | .29 | 30 | 24-38 |
| 21 | WI1 Hastings | 100 | 33 | 17 | 51 | 23 | 41 | .55 | 36 | 30-44 |
| 22 | FL1 Lobbig Apts | 100 | 9 | - | 0 | 12 | 73 | .96 | 52 | 34-79 |
| 23 | IL1 Marl | 94 | 328 | 9 | 40 | 11 | 82 | .83 | 63 | 49-94 |
| 24 | WI1 Lincoln | 91 | 30 | 15 | 57 | 16 | 91 | .95 | 66 | 46-94 |
| 25 | TN1 VC | 90 | 89 | 4 | 13 | 11 | 45 | .39 | 42 | 34-53 |
| 26 | OC1 Westleigh | 93 | 41 | 3 | 21 | 39 | 51 | .41 | 46 | 41-52 |
| 27 | 1S1 U. + 92nd | 92 | 51 | - | 37 | 11 | 176 | .98 | 126 | 80-147 |
| 28 | IL1 John S. | 91 | 10 | 16 | 19 | 29 | 111 | .80 | 87 | 69-108 |
| 29 | TN1 91 | 91 | 69 | 11 | 33 | 11 | 120 | .96 | 87 | 66-135 |
| 30 | WA1 Lake Hills | 91 | 102 | 12 | 37 | 127 | 44 | .54 | 38 | 16-41 |
| 31 | IL1 Mallrs S. | 90 | 28 | 22 | 37 | 10 | 180 | .72 | 149 | 119-178 |
| 32 | NY3 Charter Ndo | 89 | 42 | - | 16 | 12 | 56 | .64 | 47 | 35-64 |
| 33 | OC1 Lakeridge | 88 | 19 | - | 14 | 48 | 53 | .46 | 47 | 42-52 |
| 34 | OC1 Aubrey | 86 | 127 | 9 | 32 | 9 | 234 | 1.12 | 155 | 49-273 |
| 35 | IL1 Comb Inlets | 85 | 524 | 8 | 17 | 24 | 108 | .90 | 102 | 78-134 |
| 36 | MA1 Lesure | 85 | 154 | 11 | 16 | 6 | 104 | .45 | 95 | 67-135 |
| 37 | MD1 11D23 | 84 | 324 | 4 | 36 | 34 | 90 | .97 | 64 | 51-82 |
| 38 | MA1 Jordan | 79 | 110 | 10 | 21 | 9 | 79 | .53 | 70 | 51-95 |
| 39 | OC1 Gledwin | 78 | 27 | 15 | 34 | 45 | 45 | .60 | 19 | 34-45 |

| Mixed Open and Nonurban | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Site | Land Use % Open | Area (A) | Pop. Den (r/A) | % IMP. | No. of OBS | COD Mean | COD COV | COD Median | COD 90% Confidence Limits |
| 1 | FL1 Shaview | 100 | 631 | - | - | 14 | 111 | .43 | 102 | 90-123 |
| 2 | CO1 Phoney Gulch | 100 | 415 | 0 | 1 | 3 | 73 | .13 | 69 | 54-87 |
| 3 | NY1 Thornell | 100 | 25,416 | - | 4 | 8 | 25 | .10 | 31 | 18-24 |
| 4 | NY2 English R1 | 98 | 6,248 | - | 1 | 11 | - | - | - | - |
| 5 | NY2 West Br | 97 | 5,338 | - | 1 | 0 | - | - | - | - |
| 6 | NY2 Thomas Cr | 91 | 17,728 | 1 | 11 | 6 | 26 | .20 | 25 | 21-32 |
| 7 | NY3 River Cr | 90 | 2,303 | - | 6 | 5 | 25 | .10 | 15 | 21-36 |
| 8 | NY2 Shelter Cool | 80 | 552 | - | 7 | 0 | - | - | - | - |

| | Site | Land Use % | Area (A) | Pop. Den (J/A) | % IMP. | No. of OBS | COD Mean | COD COV | COD Median | COD 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | KS1 Noland | - | 16 | 3 | 66 | 12 | 106 | .56 | 89 | 55-122 |
| 2 | MD1 Hampden | - | 12 | 40 | 72 | 30 | 111 | .33 | 99 | 89-115 |
| 3 | IL1 Mattis N | - | 17 | 3 | 55 | 35 | 195 | .66 | 164 | 130-195 |
| 4 | MI1 Waverly | - | 30 | 11 | 68 | 27 | 64 | .30 | 60 | 40-61 |
| 5 | TN1 SC | - | 147 | 3 | 41 | 13 | 40 | .70 | 49 | 16-67 |
| 6 | WI1 Wood Ctr | - | 45 | 12 | 81 | 39 | 92 | .57 | 90 | 19-92 |
| 7 | MA1 Rt 9 | - | 318 | 7 | 73 | 6 | 107 | .62 | 68 | 51-146 |
| 8 | MA1 Convert | - | 100 | 3 | 73 | 8 | 72 | .62 | 61 | 40-89 |
| 9 | MI1 Grand R 01 | - | 453 | 5 | 38 | 16 | 71 | .47 | 65 | 55-76 |
| 10 | MI3 Plit AA-S | - | 2001 | 2 | 21 | 4 | - | - | - | - |
| 11 | NY2 Cedar | - | 76 | - | 5 | 0 | - | - | - | - |
| 12 | MA1 Anna | - | 601 | 9 | 12 | 6 | 89 | .61 | 76 | 53-116 |
| 13 | MI3 Plit AA-N | - | 2871 | 7 | 26 | 3 | - | - | - | - |
| 14 | MI3 Grace N | - | 164 | 5 | 26 | 17 | 72 | .43 | 68 | 55-79 |
| 15 | MI3 Swift Run | - | 1307 | 2 | 4 | 5 | 39 | .10 | 39 | 26-73 |
| 16 | SD1 Meade | - | 2030 | - | - | 14 | 179 | .39 | 167 | 140-206 |
| 17 | CA1 Knox | - | 1543 | 12 | - | 21 | 93 | .60 | 86 | 85-99 |
| 18 | FL1 N. Jaitun | - | 31 | - | 13 | 15 | 51 | 1.18 | 32 | 22-50 |
| 19 | FL1 Wilder | - | 194 | - | 97 | 11 | 51 | .38 | 48 | 41-57 |
| 20 | CO1 Nor CN Ave | - | 59 | 9 | 50 | 32 | 289 | .74 | 275 | 186-275 |

| Commercial | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Site | Land Use % Coml | Area (A) | Pop. Den (r/A) | % IMP. | No. of OBS | COD Mean | COD COV | COD Median | COD 90% Confidence Limits |
| 1 | CO1 Villa Italia | 100 | 14 | 0 | 91 | 27 | 184 | .67 | 139 | 109-178 |
| 2 | NC1 SOll [CBD] | 100 | 21 | 0 | 69 | 40 | 120 | .79 | 84 | 78-113 |
| 3 | MI3 SouthGate | 100 | 179 | 2 | 21 | 9 | 41 | .14 | 35 | 31-41 |
| 4 | MI1 Post Office | 100 | 12 | 0 | 100 | 41 | 52 | .17 | 48 | 41-55 |
| 5 | NH1 Pkg Lot | 100 | 3 | 0 | 90 | 33 | 96 | .79 | 19 | 65-98 |
| 6 | TN2 CBD | 100 | 26 | 0 | 98 | 15 | 71 | .52 | 55 | 53-81 |
| 7 | WI1 Whistler | 100 | 10 | 0 | - | 26 | 59 | .76 | 47 | 37-64 |
| 8 | 1S1 1C Metcalf | 96 | 59 | - | 97 | 26 | 35 | .86 | 41 | 12-55 |
| 9 | FL1 Norma Pt | 91 | 47 | - | 45 | 12 | 41 | .43 | 17 | 39-47 |
| 10 | WI1 State Fair | 74 | 29 | 10 | 77 | 21 | 113 | .92 | 94 | 64-117 |

| Industrial | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Site | Land Use % Ind | Area (A) | Pop. Den (r/A) | % IMP. | No. of OBS | COD Mean | COD COV | COD Median | COD 90% Confidence Limits |
| 1 | MA2 Addison | 100 | 18 | 0 | 69 | 0 | - | - | - | - |
| 2 | WI1 Indus Health | 100 | 53 | 0 | 64 | 12 | 61 | .46 | 53 | 41-77 |
| 3 | KS1 Lenexa | 56 | 22 | - | 44 | 16 | 58 | .60 | 50 | 39-64 |
| 4 | WI1 Grace S. | 52 | 75 | 5 | 39 | 11 | 60 | .79 | 47 | 37-64 |

## TABLE 6-4. SITE MEAN TOTAL P EMCs (μg/ℓ)

Residential

| | Site | Land Use % Res | Area (Ac) | Pop. Den (P/Ac) | % IMP. | No. of OBS | Total P Mean | Total P COV | Total P Median | Total P 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CO1 Big Dry Cr | 100 | 31 | 19 | 41 | 16 | 693 | .94 | 508 | 356-716 |
| 2 | CO1 Cherry | 100 | 57 | 24 | 18 | 14 | 479 | .54 | 312 | 291-479 |
| 3 | CO1 S/F Claude | 100 | 107 | 14 | 24 | 15 | 630 | .65 | 513 | 392-672 |
| 4 | DC1 Dufief | 100 | 12 | - | - | 5 | 499 | .12 | 415 | 353-640 |
| 5 | DC1 Lakeridge | 100 | 68 | 21 | 13 | 46 | 321 | .18 | 256 | 217-302 |
| 6 | DC1 Stratton | 100 | 8 | - | - | 28 | 340 | .54 | 300 | 255-351 |
| 7 | IL1 John N | 100 | 54 | 10 | 19 | 13 | 750 | .62 | 616 | 518-753 |
| 8 | KS1 Overton | 100 | 58 | 8 | 38 | 8 | 1636 | .91 | 1207 | 717-2031 |
| 9 | MA2 Hemlock | 100 | 50 | 6 | 16 | 5 | 314 | 1.05 | 236 | 95-491 |
| 10 | MD1 Bolton Hill | 100 | 14 | 30 | 53 | 19 | 912 | 1.15 | 613 | 425-883 |
| 11 | MD1 Homeland | 100 | 23 | 9 | 29 | 13 | 421 | .70 | 345 | 263-471 |
| 12 | MD1 Mt Wash | 100 | 11 | 12 | 29 | 20 | 556 | .83 | 428 | 324-566 |
| 13 | MD1 Res Mall | 100 | 10 | 55 | 76 | 13 | 4090 | 1.05 | 2825 | 1845-4326 |
| 14 | NY1 Laurel's R. | 100 | 73 | 13 | 20 | 24 | 221 | .54 | 195 | 163-233 |
| 15 | NY1 Unqua | 100 | - | - | - | 8 | 229 | .61 | 196 | 134-285 |
| 16 | NY3 Kingston | 100 | 166 | 5 | 22 | 10 | 301 | .54 | 265 | 206-340 |
| 17 | NY3 E. Rock. | 100 | 346 | 18 | 18 | 8 | 448 | .47 | 405 | 300-546 |
| 18 | TX1 Rollingwood | 100 | 60 | 3 | 21 | 9 | 268 | .56 | 231 | 169-322 |
| 19 | WA1 Surrey | 100 | 95 | 9 | 29 | 118 | 239 | .83 | 184 | 164-205 |
| 20 | WI1 Burbank | 100 | 63 | 16 | 30 | 45 | 229 | .45 | 209 | 188-231 |
| 21 | WI1 Hastings | 100 | 31 | 17 | 51 | 15 | 258 | .51 | 230 | 203-264 |
| 22 | TX1 Young Apts | 100 | 9 | - | 6 | 12 | 333 | .65 | 279 | 205-380 |
| 23 | TX1 Hart | 99 | 178 | 9 | 40 | 14 | 333 | .80 | 260 | 189-349 |
| 24 | WI1 Lincoln | 97 | 36 | 18 | 57 | 23 | 453 | .69 | 373 | 298-466 |
| 25 | TN1 RC | 98 | 81 | 4 | 11 | 11 | 246 | .41 | 222 | 185-287 |
| 26 | WA1 Westleigh | 93 | 41 | 3 | 21 | 41 | 397 | .75 | 319 | 268-380 |
| 27 | KS1 IC - 52nd | 92 | 63 | - | 37 | 10 | 1797 | 1.11 | 782 | 441-1405 |
| 28 | IL1 John S. | 91 | 33 | 18 | 38 | 32 | 732 | .65 | 604 | 502-727 |
| 29 | TN1 PI | 93 | 69 | 11 | 33 | 11 | 705 | .15 | 665 | 552-803 |
| 30 | WA1 Lake Hills | 91 | 102 | 12 | 37 | 127 | 264 | .81 | 204 | 184-227 |
| 31 | IL1 Mallss S. | 90 | 28 | 22 | 37 | 32 | 587 | .69 | 483 | 401-582 |
| 32 | FL1 Charter Hdq | 89 | 42 | - | 16 | 30 | 395 | 1.61 | 208 | 116-314 |
| 33 | MD1 Fairidge | 98 | 19 | - | 34 | 37 | 151 | .13 | 254 | 242-334 |
| 34 | CO1 Asbury | 66 | 127 | 9 | 23 | 9 | 1025 | .71 | 834 | 561-1239 |
| 35 | IL2 Comb Inlett | 86 | 524 | 8 | 17 | 26 | 506 | .79 | 391 | 314-511 |
| 36 | MA1 Locust | 85 | 154 | 31 | 16 | 6 | 3228 | .79 | 961 | 545-1717 |
| 37 | NC1 11023 | 84 | 124 | 6 | 27 | 67 | 529 | .99 | 125 | 117-444 |
| 38 | MA1 Jordan | 79 | 110 | 10 | 21 | 8 | 448 | .98 | 324 | 190-565 |
| 39 | DC1 Stedwick | 71 | 21 | 15 | 34 | 44 | 388 | .65 | 326 | 281-379 |

Urban Open and Nonurban

| | Site | Land Use % Open | Area (Ac) | Pop. Den (P/Ac) | % IMP. | No. of OBS | Total P Mean | Total P COV | Total P Median | Total P 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | [illegible] | 100 | 633 | - | - | 13 | 590 | .82 | 455 | 319-549 |
| 2 | [illegible] | 100 | 405 | 0 | 1 | 7 | 420 | .41 | 380 | 224-528 |
| 3 | [illegible] | 100 | 25,416 | - | 4 | 33 | 191 | .46 | 175 | 141-217 |
| 4 | NY2 English Br | 95 | 5,248 | - | 1 | 30 | 27 | 1.30 | 13 | [illegible] |
| 5 | NY2 West Br | 97 | 5,138 | - | 1 | 31 | 52 | 1.27 | 32 | 24-43 |
| 6 | NY3 Thomas Cr | 91 | 17,228 | 1 | 11 | 16 | 195 | .42 | 177 | 140-221 |
| 7 | NY1 Traver Cr | 90 | 7,303 | - | 6 | 5 | 91 | .36 | 85 | 50-171 |
| 8 | NY2 Sheriff Cool | 88 | 553 | - | 7 | 12 | 264 | 1.01 | 186 | 145-238 |

Mixed

| | Site | Land Use % | Area (Ac) | Pop. Den (P/Ac) | % IMP. | No. of OBS | Total P Mean | Total P COV | Total P Median | Total P 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | LS1 Noland | - | 16 | 3 | 68 | 7 | 588 | .34 | 526 | 413-671 |
| 2 | MD1 Hampden | - | 17 | 40 | 72 | 20 | 750 | 1.41 | 436 | [illegible] |
| 3 | IL1 Maltss N | - | 12 | 3 | 58 | 35 | 998 | .56 | 431 | [illegible] |
| 4 | MI1 Waverly | - | 30 | 11 | 68 | 35 | 196 | .64 | 162 | [illegible] |
| 5 | IN3 SC | - | 187 | 3 | 43 | 33 | 352 | .64 | 296 | [illegible] |
| 6 | WI1 Wood Ctr | - | 48 | 12 | 81 | 97 | 289 | .59 | 240 | 212-284 |
| 7 | MA1 Rt 9 | - | 339 | 7 | 23 | 5 | 1176 | .65 | 995 | [illegible] |
| 8 | MA1 Convent | - | 109 | 1 | 31 | 8 | 459 | 1.99 | 206 | [illegible] |
| 9 | MI1 Grand R St | - | 453 | 5 | 38 | 22 | 458 | .55 | 184 | [illegible] |
| 10 | MI3 Pitt AA-5 | - | 2001 | 2 | 21 | 6 | 103 | .50 | 91 | [illegible] |
| 11 | NI2 Cedar | - | 76 | - | 5 | 12 | 163 | 1.20 | 231 | [illegible] |
| 12 | MA1 Roma | - | 601 | 9 | 13 | [illegible] | 534 | .83 | 406 | [illegible] |
| 13 | MI3 Pitt 4A-N | - | 2871 | 7 | 26 | 6 | 268 | .47 | 243 | [illegible] |
| 14 | MI1 Grace N | - | 164 | 5 | 28 | 23 | 394 | .54 | 301 | 225-410 |
| 15 | MI3 Swift Run | - | 1207 | 2 | 4 | 5 | 134 | .56 | 117 | 21-193 |
| 16 | SD3 Meadp | - | 2030 | - | - | 15 | 1685 | 1.29 | 1153 | 743-1621 |
| 17 | CP1 Knox | - | 3542 | 12 | - | 19 | 418 | .50 | 374 | 310-451 |
| 18 | FL1 N. Detuit | - | 30 | - | 13 | 15 | 196 | .71 | 151 | 120-214 |
| 19 | FL1 Wilder | - | 194 | - | 97 | 15 | 229 | .52 | 204 | 153-255 |
| 20 | CO1 North Ave | - | 59 | 9 | 50 | 38 | 784 | .69 | 673 | 570-795 |

Commercial

| | Site | Land Use % Coml | Area (Ac) | Pop. Den (P/Ac) | % IMP. | No. of OBS | Total P Mean | Total P COV | Total P Median | Total P 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CO1 Villa Italia | 100 | 24 | 0 | 91 | 27 | 704 | 1.25 | 438 | 316-601 |
| 2 | NC1 1913 [illegible] | 100 | 13 | 0 | 69 | 51 | 395 | .56 | 342 | 304-323 |
| 3 | NY3 Southgate | 100 | 173 | 1 | 21 | 12 | 216 | .26 | 209 | 193-239 |
| 4 | WI1 Post Office | 100 | 12 | 0 | 100 | 50 | 118 | .56 | 94 | 84-105 |
| 5 | NH1 Pkg Lot | 100 | 1 | 0 | 46 | 27 | 173 | 1.21 | 114 | 137-238 |
| 6 | IN1 C&B | 100 | 26 | 0 | 99 | 15 | 212 | .43 | 195 | 162-235 |
| 7 | WI1 Rustler | 100 | 12 | 0 | - | 44 | 105 | .79 | 86 | 69-98 |
| 8 | KS1 U. Metcalf | 96 | 68 | - | 97 | 20 | 246 | .98 | 176 | 126-241 |
| 9 | FL1 Norma Fk | 91 | 47 | - | 45 | 12 | 151 | .50 | 135 | 106-172 |
| 10 | WI1 State Fair | 79 | 24 | 10 | [illegible] | 19 | 313 | 1.19 | 336 | 245-443 |

Industrial

| | Site | Land Use % Ind | Area (Ac) | Pop. Den (P/Ac) | % IMP | No. of OBS | Total P Mean | Total P COV | Total P Median | Total P 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | MA2 Addison | 100 | 18 | 3 | 69 | 5 | 114 | .89 | 85 | 41-175 |
| 2 | WI1 Index Drain | 100 | 63 | 0 | 64 | 18 | 545 | .58 | 472 | 375-589 |
| 3 | KS1 Lenexa | 98 | 72 | - | 44 | 16 | 591 | .87 | 452 | 315-616 |
| 4 | NC1 Graphic S. | 62 | 25 | 5 | 19 | 17 | 435 | .11 | 385 | 271-455 |

**Residential**

| | Site | Land Use % Res | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | SOL P Mean | SOL P COV | SOL P Median | SOL P 90% Confidence limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CO1 Blg Dry Cr | 100 | 33 | 19 | 41 | 15 | 193 | .64 | 163 | 125-213 |
| 2 | CO1 Cherry | 100 | 57 | 24 | 38 | 14 | 212 | .47 | 192 | 155-237 |
| 3 | CO1 116/Claude | 100 | 167 | 14 | 24 | 16 | 196 | .35 | 179 | 154-208 |
| 4 | DC1 Duflef | 100 | 12 | - | - | 6 | 448 | .55 | 392 | 257-598 |
| 5 | DC1 taker!dge | 100 | 68 | 21 | 33 | 47 | 69 | .62 | 59 | 51-68 |
| 6 | DC1 Stratlon | 100 | 8 | - | - | 27 | 251 | .65 | 210 | 173-256 |
| 7 | IL1 John N | 100 | 54 | 18 | 19 | 0 | - | - | - | - |
| 8 | KS1 Overton | 100 | 58 | 8 | 38 | 8 | 313 | 41 | 290 | 223-378 |
| 9 | MA2 Nemloct | 100 | 50 | 5 | 16 | 5 | 16[illegible] | .89 | 120 | 58-249 |
| 10 | MD1 Bnlton Hill | 100 | 14 | 30 | 51 | [illegible] | - | - | - | - |
| 11 | MD1 Home7and | 100 | 23 | 9 | 29 | 0 | - | - | - | - |
| 12 | MD1 Mt Wasn | 100 | 17 | 12 | 29 | 0 | - | - | - | - |
| 13 | MD1 Pes Hill | 100 | 10 | 55 | 76 | 0 | - | - | - | - |
| 14 | NY1 Carll's R. | 100 | 73 | 13 | 20 | 0 | - | - | - | - |
| 15 | NY1 Unqua | 100 | - | - | - | 0 | - | - | - | - |
| 16 | NY3 Cranston | 100 | 166 | 5 | 22 | 0 | - | - | - | - |
| 17 | NY1 E. Roch. | 100 | 346 | 18 | 38 | 0 | - | - | - | - |
| 18 | TX1 Rollingwood | 100 | 60 | 3 | 21 | 0 | - | - | - | - |
| 19 | WA1 Surrey | 100 | 95 | 9 | 29 | 0 | - | - | - | - |
| 20 | WI1 Burbant | 100 | 63 | 15 | 50 | 0 | - | - | - | - |
| 21 | WI1 Haslings | 100 | 33 | 17 | 51 | 0 | - | - | - | - |
| 22 | FL1 Young Apls | 100 | 9 | - | 6 | 0 | - | - | - | - |
| 23 | TX1 Hart | 99 | 378 | 9 | 40 | 0 | - | - | - | - |
| 24 | WI1 Lincoln | 97 | 36 | 18 | 57 | 0 | - | - | - | - |
| 25 | TN1 P2 | 96 | 89 | 4 | 13 | 11 | 132 | .63 | 112 | 82-154 |
| 26 | DC1 Westleigh | 93 | 41 | 3 | 21 | 41 | 223 | .71 | 182 | 154-215 |
| 27 | KS1 IC - 92nd | 92 | 63 | - | 37 | 10 | 241 | .62 | 205 | 147-285 |
| 28 | IL1 John S. | 91 | 19 | 18 | 18 | 0 | - | - | - | - |
| 29 | TN1 R1 | 91 | 69 | 11 | 33 | 11 | 136 | .94 | 99 | 64-153 |
| 30 | WA1 Lake Hills | 91 | 102 | 12 | 37 | 0 | - | - | - | - |
| 31 | IL1 Mattis S. | 90 | 28 | 22 | 37 | 0 | - | - | - | - |
| 32 | FL1 Charler Mdg | 89 | 42 | - | 16 | 0 | - | - | - | - |
| 33 | DC1 Falrldge | 88 | 19 | - | 34 | 46 | 297 | .87 | 224 | 186-270 |
| 34 | CO1 Asbury | 86 | 127 | 9 | 22 | 9 | 212 | .22 | 207 | 181-232 |
| 35 | IL2 Comb Inlets | 85 | 524 | 8 | 17 | 24 | 98 | 1.21 | 63 | 95-88 |
| 36 | NH1 Locust | 85 | 154 | 11 | 16 | 6 | 184 | .42 | 169 | 121-235 |
| 37 | NY1 #1023 | 84 | 324 | 6 | 22 | 0 | - | - | - | - |
| 38 | MA1 Jordan | 79 | 110 | 10 | 21 | 7 | 202 | 1.11 | 136 | 70-262 |
| 39 | DC1 Stedwick | 78 | 22 | 15 | 34 | 41 | 251 | .70 | 206 | 174-243 |

**Urban Open and Nonurban**

| | Site | Land Use % Open | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | SOL P Mean | SOL P COV | SOL P Median | SOL P 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CA1 Gravlow | 100 | 633 | - | - | 12 | 145 | 1.20 | 91 | 55-150 |
| 2 | CO1 Rooney Gulch | 100 | 405 | 0 | 1 | 7 | 137 | .46 | 124 | 90-171 |
| 3 | NY3 Thornell | 100 | 28,416 | - | 4 | 0 | - | - | - | - |
| 4 | NY2 English Br | 98 | 5,248 | - | 1 | 18 | 5 | .35 | 5 | 4-6 |
| 5 | NY2 West Br | 93 | 5,138 | - | 1 | 26 | 8 | .56 | 7 | 6-8 |
| 6 | NY1 Thomas Cr | 91 | 17,728 | 1 | 11 | 0 | - | - | - | - |
| 7 | MI3 Travel Cr | 90 | 2,301 | - | 6 | 5 | 31 | .55 | 29 | 18-47 |
| 8 | NY2 Sheriff Duck | 80 | 552 | - | 7 | 12 | 39 | 1.11 | 25 | 20-14 |

**Mixed**

| | Site | Land Use % | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | SOL P Mean | SOL P COV | SOL P Median | SOL P 90% Confidence limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | KS1 Noland | - | 36 | 3 | 68 | 8 | 165 | .52 | 146 | 105-203 |
| 2 | MD1 Hampden | - | 17 | 40 | 72 | 0 | - | - | - | - |
| 3 | IL1 Mattis N | - | 17 | 3 | 58 | 0 | - | - | - | - |
| 4 | MI1 Waverly | - | 30 | 11 | 68 | 32 | 43 | .76 | 34 | 28-42 |
| 5 | TN1 SC | - | 187 | 3 | 43 | 13 | 197 | 1.17 | 128 | 81-203 |
| 6 | WI1 Wood Ctr | - | 45 | 12 | 81 | 0 | - | - | - | - |
| 7 | MA1 Rt 9 | - | 338 | 7 | 23 | 5 | 160 | .38 | 150 | 106-213 |
| 8 | MA1 Convent | - | 100 | 1 | 33 | 6 | 106 | 1.83 | 51 | 19-138 |
| 9 | MI1 Grand R Ot | - | 453 | 5 | 38 | 20 | 68 | .68 | 56 | 44-71 |
| 10 | MI3 Pitt AA-S | - | 2001 | 2 | 21 | 6 | 13 | .37 | 13 | 10-17 |
| 11 | NY2 Cedar | - | 76 | - | 5 | 26 | 49 | 1.16 | 32 | 23-44 |
| 12 | MA1 Anna | - | 601 | 9 | 12 | 4 | - | - | - | - |
| 13 | MI3 Pitt AA-N | - | 2871 | 7 | 26 | 6 | 59 | .88 | 44 | 24-82 |
| 14 | MI1 Grace N | - | 164 | 5 | 28 | 21 | 47 | .47 | 42 | 35-50 |
| 15 | MI3 Swift Run | - | 1207 | 2 | 4 | 5 | 39 | .46 | 35 | 23-53 |
| 16 | SD1 Meade | - | 2030 | - | - | 14 | 87 | .61 | 74 | 57-97 |
| 17 | CA1 Knox | - | 1542 | 12 | - | 18 | 169 | .99 | 120 | 85-168 |
| 18 | FL1 N. Jesuit | - | 30 | - | 13 | 0 | - | - | - | - |
| 19 | FL1 Wilder | - | 194 | - | 97 | 0 | - | - | - | - |
| 20 | CO1 North Ave | - | 69 | 9 | 50 | 30 | 228 | .95 | 165 | 179-212 |

**Commercial**

| | Site | Land Use % Coml | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | SOL P Mean | SOL P COV | SOL P Median | SOL P 90% Confidence limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CO1 Villa Italia | 100 | 24 | 0 | 91 | 26 | 293 | 1.09 | 198 | 147-266 |
| 2 | NC1 1013 (CBO) | 100 | 23 | 0 | 69 | 0 | - | - | - | - |
| 3 | NY3 Southgate | 100 | 179 | 2 | 21 | 0 | - | - | - | - |
| 4 | WI1 Post Office | 100 | 12 | 0 | 100 | 0 | - | - | - | - |
| 5 | NH1 Pkg Lot | 100 | 1 | 0 | 90 | 0 | - | - | - | - |
| 6 | TN1 CBO | 100 | 26 | 0 | 99 | 15 | 46 | .72 | 17 | 28-50 |
| 7 | WI1 Rustler | 100 | 12 | 0 | - | 0 | - | - | - | - |
| 8 | KS1 IC Metcalf | 96 | 58 | - | 97 | 21 | 116 | 1.06 | 80 | 58-111 |
| 9 | FL1 Norma Pt | 91 | 47 | - | 45 | 0 | - | - | - | - |
| 10 | WI1 State Fair | 74 | 29 | 10 | 77 | 0 | - | - | - | - |

**Industrial**

| | Site | Land Use % Ind | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | SOL P Mean | SOL P COV | SOL P Median | SOL P 90% Confidence limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | MA2 Addison | 100 | 18 | 0 | 69 | 5 | 75 | .92 | 55 | 26-116 |
| 2 | MI2 Indus Drain | 100 | 63 | 0 | 64 | 14 | 127 | .72 | 103 | 76-140 |
| 3 | KS1 Lenexa | 56 | 72 | - | 44 | 16 | 346 | 1.66 | 179 | 108-296 |
| 4 | MI1 Grace S. | 52 | 75 | 5 | 39 | 16 | 59 | 1.24 | 37 | 24-56 |

# TABLE 6-6. SITE MEAN TKN EMCs (μg/ℓ)

**Residential**

| | Site | Land Use % Res | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | TKN Mean | TKN COV | TKN Median | TKN 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CO1 Big Dry Cr | 100 | 31 | 19 | 41 | 16 | 2,169 | .58 | 2041 | 1617-2584 |
| 2 | CO1 Cherry | 100 | 57 | 24 | 38 | 14 | 2,609 | .39 | 2430 | 2014-2904 |
| 3 | CO1 116/Claude | 100 | 167 | 14 | 74 | 15 | 2,891 | .51 | 2501 | 2010-1112 |
| 4 | DC1 Dufief | 100 | 17 | - | - | 6 | 2,066 | .11 | 2048 | 1841-2278 |
| 5 | DE1 Lakeridge | 100 | 68 | 21 | 33 | 48 | 1,774 | .64 | 1450 | 1259-1670 |
| 6 | DC1 Stratton | 100 | 8 | - | - | 28 | 1,811 | .34 | 1696 | 1494-1904 |
| 7 | IL1 John N | 100 | 54 | 18 | 19 | 13 | 1,994 | .81 | 1107 | 7520-3811 |
| 8 | KS1 Overton | 100 | 58 | 8 | 38 | 5 | - | - | - | - |
| 9 | MA2 Hemlock | 100 | 50 | 5 | 16 | 5 | 1,679 | .55 | 1217 | 1971-5252 |
| 10 | MD1 Bolton Hilt | 100 | 14 | 30 | 51 | 18 | 6,067 | .17 | 4815 | 1640-6170 |
| 11 | MD1 Homeland | 100 | 21 | 9 | 79 | 13 | 6,505 | .40 | 6044 | 4996-7112 |
| 12 | MD1 Mt Wash | 100 | 17 | 12 | 29 | 70 | 6,915 | .41 | 6408 | 5502-7461 |
| 13 | MD1 Res Hill | 100 | 10 | 55 | 76 | 13 | 10,803 | .41 | 9915 | 9089-12154 |
| 14 | NH1 Carll's R. | 100 | 71 | 11 | 20 | 24 | 1,487 | .71 | 1201 | 955-1509 |
| 15 | NY1 Unqua | 100 | - | - | - | 8 | 1,408 | .26 | 1161 | 1148-1618 |
| 16 | NH1 Cranston | 100 | 166 | 5 | 77 | 11 | 1,492 | .45 | 1358 | 1098-1679 |
| 17 | NY3 E. Roch. | 100 | 346 | 18 | 18 | 7 | 3,246 | .90 | 7411 | 1369-4245 |
| 18 | IL1 Rollingwood | 100 | 60 | 1 | 71 | 9 | 5,004 | 2.37 | 1942 | 828-4554 |
| 19 | WA1 Surrey | 100 | 95 | 9 | 29 | 118 | 1,007 | .62 | 857 | 785-915 |
| 20 | WI1 Burbank | 100 | 61 | 15 | 50 | | 1,260 | .50 | 1125 | 908-1195 |
| 21 | WI1 Hastings | 100 | 13 | 17 | 51 | 15 | 1,102 | .54 | 969 | 801-1173 |
| 22 | FL1 Young Apts | 100 | 9 | - | 6 | 12 | 1,139 | .70 | 1097 | 791-1522 |
| 23 | TX1 Hart | 99 | 178 | 9 | 40 | 11 | 1,016 | .75 | 2412 | 1674-3474 |
| 24 | WI1 Lincoln | 37 | 16 | 18 | 57 | 1 | - | - | - | - |
| 25 | TN1 P2 | 96 | 84 | 4 | 11 | 11 | 476 | .11 | 452 | 379-519 |
| 26 | DE1 Westleigh | 93 | 41 | 3 | 21 | 41 | 1,901 | .56 | 1660 | 1447-1904 |
| 27 | KS1 JC - 47nd | 92 | 61 | - | 17 | 8 | 4,187 | .94 | 3051 | 1793-5200 |
| 28 | IL1 John S. | 41 | 19 | 18 | 18 | 12 | 1,527 | 1.04 | 2441 | 1886-1155 |
| 29 | FN1 P1 | 91 | 69 | 11 | 11 | 11 | 1,131 | .14 | 1071 | 894-1281 |
| 30 | WP1 Lake Hills | 91 | 102 | 12 | 37 | 127 | 1,056 | .71 | 852 | 774-438 |
| 31 | IL1 Mattis S. | 90 | 28 | 77 | 27 | 37 | 1,440 | .69 | 2825 | 2343-3406 |
| 32 | FL1 Charter Hdg | 89 | 42 | - | 16 | 12 | 1,704 | .83 | 1309 | 899-1905 |
| 33 | DC1 Fairidge | 88 | 19 | - | 34 | 46 | 2,712 | .51 | 1958 | 1711-2215 |
| 34 | CO1 Asbury | 86 | 177 | 9 | 72 | t | 3,735 | .56 | 3761 | 7774-4788 |
| 35 | IL2 Cobb Intets | 85 | 524 | 6 | 17 | 0 | - | - | - | - |
| 36 | MP1 Locust | 85 | 154 | 11 | 16 | 6 | 2,695 | .38 | 2522 | 1864-3412 |
| 37 | NC1 #1021 | 84 | 324 | F | 73 | 67 | 1,488 | .94 | 1086 | 921-1277 |
| 38 | WA1 Jordan | 79 | 110 | 10 | 21 | 9 | 1,191 | .60 | 1194 | 845-1682 |
| 39 | DC1 Stedwick | 78 | 27 | 15 | 34 | 43 | 1,895 | .57 | 1543 | 1435-1881 |

**Urban Open and Nonurban**

| | Site | Land Use % Open | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | TKN Mean | TKN COV | TKN Median | TKN 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | WA1 Seaview | 100 | 613 | - | - | 13 | 3674 | .59 | 1159 | 7411-4139 |
| 2 | CO1 Rooney Gulch | 105 | 405 | 0 | 1 | 7 | 7954 | .57 | 7615 | 1813-3768 |
| 3 | NY1 Hornell | 100 | 28,416 | - | 4 | 11 | 1099 | .50 | 482 | 778-1240 |
| 4 | NY2 English Br | 98 | 5,248 | - | 1 | 15 | 340 | .50 | 305 | 246-178 |
| 5 | NH2 West Br | 97 | 5,338 | - | 1 | 24 | 392 | .57 | 147 | 792-412 |
| 6 | NH1 Thomas Br | 91 | 17,728 | 1 | 11 | 10 | 1111 | .16 | 1045 | 854-1279 |
| 7 | MI3 Fraser Cr | 90 | 2,101 | - | 6 | 5 | 889 | .11 | 883 | 796-981 |
| 8 | NY7 Sheriff Dock | 80 | 552 | - | 7 | 13 | 963 | .76 | 765 | 628-937 |

**Mixed**

| | Site | Land Use % | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | TKN Mean | TKN COV | TKN Median | TKN 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | KS1 Noland | - | 36 | 3 | 68 | 0 | - | - | - | - |
| 2 | MD1 Hampden | - | 17 | 40 | 72 | 19 | 6994 | .55 | 6140 | 5004-7531 |
| 3 | IL1 Mattis N | - | 17 | 3 | 58 | 15 | 2872 | .64 | 2172 | 7006-7805 |
| 4 | WI1 Waverly | - | 10 | 11 | 68 | 15 | 1490 | .51 | 1116 | 1142-1516 |
| 5 | TN1 SC | - | 187 | 1 | 41 | 11 | 623 | .50 | 558 | 442-705 |
| 6 | WI1 Wood Ctr | - | 45 | 12 | 81 | 16 | 1452 | .35 | 1369 | 1180-1589 |
| 7 | MA1 Rt 9 | - | 338 | 7 | 23 | 5 | 2446 | .50 | 2188 | 1194-1412 |
| 8 | MA1 Convent | - | 100 | 1 | 33 | 8 | 1080 | .64 | 910 | 615-1147 |
| 9 | WI1 Grand R Ot | - | 451 | 5 | 18 | 21 | 1631 | .47 | 1506 | 1104-1740 |
| 10 | WI1 Pitt AA-5 | - | 7001 | 2 | 21 | 6 | 845 | .79 | 811 | 647-1025 |
| 11 | NY2 Cedar | - | 76 | - | 5 | 21 | 1237 | .81 | 951 | 724-1749 |
| 12 | MA1 Anna | - | 601 | 9 | 12 | 6 | 1888 | .70 | 1547 | 920-7601 |
| 13 | MI3 Pitt AA-N | - | 2871 | 7 | 76 | 6 | 1056 | .22 | 1011 | 867-1219 |
| 14 | WI1 Grace N | - | 164 | 5 | 28 | 21 | 1988 | .87 | 1807 | 1536-2115 |
| 15 | MI3 Swift Run | - | 1707 | 2 | 4 | 5 | 1116 | .15 | 1104 | 958-1773 |
| 16 | SD1 Meade | - | 2010 | - | - | 11 | 4741 | .50 | 1807 | 3010-4807 |
| 17 | CA1 Knox | - | 1542 | 17 | - | 70 | 2770 | .75 | 1775 | 1171-2298 |
| 18 | FL1 N. Jesuit | - | 30 | - | 11 | 15 | 1388 | .49 | 1244 | 1011-1542 |
| 19 | FL1 Wilder | - | 194 | - | 47 | 15 | 1107 | .11 | 1056 | 970-1212 |
| 20 | CO1 North Ave | - | 69 | 4 | 50 | 71 | 4196 | .65 | 1522 | 2847-4166 |

**Commercial**

| | Site | Land Use % Com | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | TKN Mean | TKN COV | TKN Median | TKN 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CO1 Villa Italia | 100 | 74 | 0 | 91 | 77 | 1657 | .85 | 2785 | 2186-3548 |
| 2 | NC1 1011 (CBD) | 100 | 71 | 0 | 64 | 61 | 1611 | .10 | 1118 | 1157-1609 |
| 3 | NY1 Southgate | 100 | 174 | 2 | 21 | 13 | 1256 | .45 | 1144 | 975-1414 |
| 4 | WI1 Post Office | 100 | 12 | 0 | 100 | 27 | 1021 | .44 | 916 | 915-1035 |
| 5 | NH1 Pkg Lot | 100 | 1 | 0 | 47 | 18 | 7110 | .66 | 1761 | 1116-7754 |
| 6 | TN1 EBO | 100 | 26 | 0 | 99 | 15 | 646 | .41 | 597 | 499-714 |
| 7 | WI1 Rustler | 100 | 12 | 0 | - | 75 | 1073 | .61 | 916 | 754-1110 |
| 8 | KS1 JC Metcalf | 96 | 58 | - | 47 | 17 | 1175 | .71 | 949 | 720-1257 |
| 9 | FL1 Norma Pk | 91 | 47 | - | 45 | 12 | 876 | .84 | 633 | 437-925 |
| 10 | WI1 State Fair | 74 | 29 | 10 | 77 | 8 | 1656 | .65 | 1189 | 913-2068 |

**Industrial**

| | Site | Land Use % Ind | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | TKN Mean | TKN COV | TKN Median | TKN 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | MA2 Addison | 100 | 18 | 0 | 69 | 5 | 7042 | .49 | 1879 | 1277-2474 |
| 2 | WI1 Indus Drain | 100 | 63 | 0 | 64 | 18 | 1274 | .57 | 1107 | 891-1376 |
| 3 | KS1 Lenexa | 56 | 72 | - | 44 | 17 | 1385 | .71 | 1117 | 796-1568 |
| 4 | WI1 Grace S. | 52 | 75 | 5 | 39 | 18 | 1711 | .56 | 1491 | 1205-1850 |

# TABLE 6-7. SITE MEAN NITRITE PLUS NITRATE EMCs (μg/ℓ)

**Residential**

| | Site | Land Use % Res | Area (A) | Pop. Den (4/A) | % IMP. | No. of OBS | $NO_{2+3}$-N Mean | COV | Median | 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CO1 Big Dry Cr | 100 | 33 | 19 | 41 | 15 | 527 | .34 | 499 | 429-580 |
| 2 | CO2 Cherry | 100 | 57 | 24 | 38 | 14 | 709 | .40 | 657 | 542-288 |
| 3 | CO1 116/Claude | 100 | 167 | 14 | 24 | 16 | 670 | .51 | 529 | 469-715 |
| 4 | DC3 Dufief | 100 | 12 | - | - | 8 | 420 | .35 | 445 | 354-558 |
| 5 | DC1 Lakeridge | 100 | 68 | 21 | 33 | 49 | 246 | .62 | 633 | 552-725 |
| 6 | DC1 Stratton | 100 | 8 | - | - | 33 | 418 | .86 | 312 | 254-395 |
| 7 | IL1 John K | 100 | 54 | 18 | 14 | - | - | - | - | - |
| 8 | KS1 Overlon | 100 | 58 | 8 | 38 | - | - | - | - | - |
| 9 | MA2 Memlock | 100 | 50 | 5 | 16 | 4 | - | - | - | - |
| 10 | MD1 Bolton Hill | 100 | 14 | 10 | 52 | 19 | 9535 | 1.59 | 5073 | 3246-7930 |
| 11 | MD1 Homeland | 100 | 23 | 9 | 29 | 13 | 6343 | 4.56 | 1358 | 570-3234 |
| 12 | MD1 Mt Wash | 100 | 17 | 12 | 29 | 20 | 7822 | 1.56 | 4229 | 2253-6492 |
| 13 | MD1 Res Mill | 100 | 10 | 55 | 26 | 13 | 6938 | 1.08 | 4207 | 1048-2269 |
| 14 | NY1 Carll's P. | 100 | 73 | 13 | 20 | 24 | 230 | 1.38 | 442 | 316-627 |
| 15 | NY1 Pnqoa | 100 | - | - | - | 8 | 1593 | - | - | 1020-1872 |
| 16 | NY3 Cranston | 100 | 166 | 5 | 22 | 0 | - | - | - | - |
| 12 | NY3 E. Roch. | 100 | 346 | 18 | 38 | 0 | - | - | - | - |
| 18 | TX1 Rollingwood | 100 | 60 | 3 | 21 | 9 | 829 | .51 | 283 | 581-1055 |
| 19 | WA1 Surrey | 100 | 95 | 9 | 79 | 0 | - | - | - | - |
| 20 | WI1 Burbank | 100 | 63 | 15 | 50 | 18 | 275 | .48 | 699 | 580-843 |
| 21 | WI1 Hastings | 100 | 13 | 17 | 51 | 24 | 625 | .39 | 582 | 510-664 |
| 22 | FL1 Young Apts | 100 | 9 | - | 6 | 12 | 311 | .64 | 262 | 193-355 |
| 23 | TX1 Hart | 99 | 328 | 9 | 40 | 10 | 1625 | .54 | 1430 | 1062-1912 |
| 24 | WS1 Lincoln | 97 | 36 | 18 | 57 | 3 | - | - | - | - |
| 25 | IN1 R2 | 96 | 89 | 4 | 19 | 11 | 997 | 1.34 | 232 | 136-412 |
| 26 | DC1 Westleigh | 93 | 41 | 9 | 71 | 41 | 202 | .59 | 606 | 525-700 |
| 22 | KS1 IC - 92nd | 92 | 63 | - | 37 | 0 | - | - | - | - |
| 28 | IL1 John S. | 91 | 39 | 18 | 18 | 0 | - | - | - | - |
| 29 | IN1 R1 | 91 | 69 | 11 | 33 | 21 | 578 | .72 | 458 | 315-665 |
| 30 | WA1 Lake Hills | 91 | 102 | 12 | 37 | 0 | - | - | - | - |
| 31 | IL1 Mallbs S. | 90 | 28 | 22 | 37 | 0 | - | - | - | - |
| 32 | FL1 Charter Mdg | 89 | 42 | - | 16 | 12 | 610 | .77 | 483 | 139-688 |
| 33 | DC1 Fairidge | 88 | 19 | - | 34 | 48 | 927 | .66 | 772 | 667-893 |
| 34 | CO1 Asbury | 86 | 122 | 9 | 22 | 9 | 881 | .21 | 862 | 258-980 |
| 35 | IL2 Comb Inlets | 85 | 524 | 8 | 12 | 21 | 296 | .55 | 699 | 526-848 |
| 36 | MA1 Locust | 65 | 154 | 11 | 16 | 5 | 1705 | .69 | 1406 | 726-2549 |
| 37 | NC1 41023 | 84 | 324 | 6 | 27 | 67 | 716 | .68 | 591 | 521-620 |
| 18 | MA1 Jordan | 79 | 110 | 10 | 21 | 9 | 1747 | .55 | 1094 | 295-1505 |
| 39 | DC2 Stedwick | 78 | 27 | 15 | 34 | 47 | 837 | .70 | 686 | 588-800 |

**Urban Open and Nonurban**

| | Site | Land Use % Open | Area (A) | Pop. Den (4/A) | % IMP. | No. of OBS | $NO_{2+3}$-N Mean | COV | Median | 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CA1 Seaview | 100 | 611 | - | - | 12 | 1542 | .49 | 1381 | 1087-1759 |
| 2 | CO1 Rooney Gulch | 100 | 405 | 51 | 1 | 7 | 581 | 1.03 | 405 | 717-756 |
| 3 | NY3 Thornell | 100 | 28,416 | - | 4 | 5 | - | - | - | - |
| 4 | NY2 English Br | 98 | 5,248 | - | 1 | 30 | 240 | .60 | 206 | 173-245 |
| 5 | NY2 West Br | 97 | 5,338 | - | 1 | 11 | 862 | .53 | 761 | 656-868 |
| 6 | NY3 Thomas Cr | 91 | 17,278 | 5 | 11 | 0 | - | - | - | - |
| 7 | MI3 Traver Cr | 90 | 2,303 | - | 6 | 5 | 1108 | .17 | 1092 | 930-1283 |
| 8 | NY2 Sheriff Pocy | 85 | 552 | - | 7 | 33 | 383 | 1.02 | 268 | 209-143 |

**Mixed**

| | Site | Land Use % | Area (A) | Pop. Den (4/A) | % IMP. | No. of OBS | $NO_{2+3}$-N Mean | COV | Median | 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | KS1 Noland | - | 36 | 3 | 68 | 0 | - | - | - | - |
| 2 | MD1 Hampden | - | 17 | 40 | 72 | 20 | 11,529 | 4.00 | 2293 | 1457-5355 |
| 1 | IL1 Mallis N | - | 17 | 3 | 58 | 0 | - | - | - | - |
| 4 | WI1 Waverly | - | 30 | 11 | 68 | 35 | 725 | .49 | 696 | 610-794 |
| 5 | TN1 SC | - | 187 | 3 | 43 | 13 | 582 | 1.49 | 327 | 192-558 |
| 6 | WI1 Wood Cir | - | 45 | 12 | 81 | 17 | 252 | .69 | 618 | 474-805 |
| 2 | MA1 Rt 9 | - | 338 | 7 | 23 | 5 | 1,789 | .48 | 1613 | 1045-2490 |
| 8 | MA1 Convent | - | 100 | 1 | 13 | 6 | 960 | .39 | 894 | 656-1218 |
| 9 | MI1 Grand R Ot | - | 453 | 5 | 38 | 23 | 883 | .44 | 807 | 694-938 |
| 10 | MI3 Pitt AA-S | - | 2001 | 2 | 21 | 6 | 284 | .48 | 256 | 276-322 |
| 11 | NY2 Cedar | - | 26 | - | 5 | 32 | 248 | .72 | 201 | - |
| 12 | MA1 Anna | - | 601 | 9 | 52 | 6 | 1,268 | .60 | 1086 | 688-1214 |
| 13 | MI3 Pitt AA-N | - | 2821 | 7 | 26 | 5 | 469 | .24 | 456 | 364-571 |
| 14 | WI1 Grace N | - | 164 | 5 | 28 | 21 | 825 | .43 | 803 | 693-931 |
| 15 | MI3 Swift Run | - | 1202 | 7 | 4 | 5 | 1,033 | .26 | 821 | 431-1563 |
| 16 | SD1 Meade | - | 2030 | - | - | 15 | 616 | .40 | 521 | 429-680 |
| 12 | CA1 Knoa | - | 1542 | 12 | - | 17 | 1,111 | .36 | 1044 | 901-1210 |
| 18 | FL1 N. Jasoll | - | 30 | - | 13 | 14 | 126 | .54 | 392 | 261-422 |
| 19 | FL1 Wilder | - | 194 | - | 92 | 15 | 456 | .42 | 412 | 336-505 |
| 20 | CO1 North Ave | - | 69 | 9 | 50 | 32 | 1,744 | .92 | 1286 | 1012-1626 |

**Commercial**

| | Site | Land Use % Coml | Area (A) | Pop. Den (4/A) | % IMP. | No. of OBS | $NO_{2+3}$-N Mean | COV | Median | 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CO1 Villa Italia | 100 | 74 | 0 | 91 | 27 | 1180 | .86 | 895 | 709-1143 |
| 2 | NC1 1013 (CBD) | 100 | 23 | 0 | 69 | 61 | 1518 | .55 | 980 | 878-1098 |
| 3 | NY3 Southgate | 100 | 129 | 2 | 21 | 0 | - | - | - | - |
| 4 | WS1 Post Office | 100 | 12 | 0 | 100 | 28 | 708 | .68 | 584 | 479-712 |
| 5 | NH1 Pkg Lot | 100 | 15 | 0 | 90 | 28 | 801 | .84 | 615 | 486-778 |
| 6 | TN1 TBD | 100 | 26 | 0 | 99 | 15 | 662 | .62 | 562 | 434-778 |
| 7 | WI1 Rustler | 100 | 12 | 0 | - | 25 | 781 | .69 | 642 | 527-791 |
| 8 | KS1 IC Metcalf | 96 | 58 | - | 97 | 0 | - | - | - | - |
| 9 | FL1 Norma Pk | 91 | 42 | - | 45 | 12 | 356 | .46 | 323 | 257-405 |
| 10 | WI1 State Fair | 74 | 29 | 10 | 72 | 12 | 781 | .50 | 702 | 540-897 |

**Industrial**

| | Site | Land Use % Ind | Area (A) | Pop. Den (4/A) | % IMP. | No. of OBS | $NO_{2+3}$-N Mean | COV | Median | 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | MA2 Addison | 100 | 18 | 5 | 69 | 5 | 1355 | .79 | 1301 | 997-1706 |
| 2 | MI1 Indus Drain | 100 | 63 | 0 | 64 | 18 | 686 | .40 | 637 | 588-746 |
| 3 | KS1 Lenexa | 56 | 72 | - | 44 | 0 | - | - | - | - |
| 4 | WI1 Grace S. | 52 | 75 | 5 | 39 | 12 | 742 | .52 | 657 | 534-808 |

# TABLE 6-8. SITE MEAN TOTAL COPPER EMCs (μg/ℓ)

**Residential**

| | Site | Land Use % Res | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | Total Copper Mean | Total Copper COV | Total Copper Median | Total Copper 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CO1 Big Dry Cr | 100 | 33 | 19 | 41 | 16 | 32 | .82 | 25 | 18-34 |
| 2 | CO1 Cherry | 100 | 57 | 24 | 38 | 14 | 35 | 1.48 | 20 | 12-33 |
| 3 | CO1 116/Claude | 100 | 157 | 14 | 24 | 16 | 28 | .74 | 22 | 16-29 |
| 4 | DC1 Dufief | 100 | 12 | - | - | 21 | - | - | - | - |
| 5 | DC1 Lakeridge | 100 | 68 | 21 | 33 | 14 | 18 | .55 | 33 | 26-42 |
| 6 | DC1 Stratton | 100 | 8 | - | - | 10 | 28 | .18 | 27 | 23-32 |
| 7 | IL1 John N | 100 | 54 | 18 | 19 | 36 | 83 | .85 | 63 | 51-78 |
| 8 | KS1 Overton | 100 | 58 | 8 | 38 | 12 | 91 | .50 | 81 | 93-101 |
| 9 | MA1 Hemlock | 100 | 50 | 5 | 16 | 0 | - | - | - | - |
| 10 | MD1 Bolton Hill | 100 | 14 | 10 | 51 | 19 | 107 | .70 | 88 | 68-112 |
| 11 | MD1 Homeland | 100 | 23 | 9 | 79 | 13 | 312 | .14 | 296 | 252-349 |
| 12 | MD1 Mt Wash | 100 | 12 | 12 | 29 | 20 | 26 | .78 | 20 | 15-26 |
| 13 | MI1 Ves Hill | 100 | 10 | 65 | 76 | 13 | 42 | .59 | 38 | 25-46 |
| 14 | NY1 Carll's R. | 100 | 71 | 13 | 20 | 0 | - | - | - | - |
| 15 | NY1 Unqua | 100 | - | - | - | 0 | - | - | - | - |
| 16 | NH3 Cranston | 100 | 166 | 5 | 22 | 0 | - | - | - | - |
| 17 | NH3 E. Apon. | 150 | 246 | 18 | 38 | 0 | - | - | - | - |
| 18 | TX1 Rollingwood | 100 | 60 | 1 | 21 | 0 | - | - | - | - |
| 19 | WA1 Surrey | 100 | 95 | 9 | 29 | 0 | - | - | - | - |
| 20 | WI1 Burbank | 100 | 61 | 15 | 50 | 0 | - | - | - | - |
| 21 | WI1 Mastinus | 100 | 31 | 17 | 51 | 0 | - | - | - | - |
| 22 | FL1 Young Apts | 100 | 4 | - | 6 | 12 | 6 | .36 | 6 | 5-7 |
| 23 | TX1 Marl | 99 | 328 | 9 | 40 | 0 | - | - | - | - |
| 24 | WI1 Lincoln | 97 | 16 | 18 | 53 | 0 | - | - | - | - |
| 25 | TN1 P2 | 96 | 89 | 4 | 13 | 11 | 28 | 1.54 | 15 | 8-22 |
| 26 | DC1 Westleigh | 93 | 41 | 3 | 21 | 6 | 31 | .43 | 34 | 24-40 |
| 27 | KS1 Jt - 9Fna | 92 | 61 | - | 17 | 2 | - | - | - | - |
| 28 | IL1 John S. | 91 | 39 | 18 | 18 | 16 | 43 | .84 | 33 | 26-40 |
| 29 | TN1 P1 | 91 | 69 | 11 | 13 | 11 | 61 | .60 | 52 | 30-70 |
| 30 | WA1 Lake Hills | 91 | 102 | 12 | 37 | 3 | 22 | .34 | 21 | 15-29 |
| 31 | IL1 Mailis S. | 90 | 28 | 22 | 37 | 36 | 45 | .76 | 36 | 30-44 |
| 32 | IL1 Charing Ndq | 89 | 42 | - | 16 | 12 | 10 | .94 | 1 | 6-11 |
| 33 | DC1 Fairridge | 88 | 39 | - | 34 | 9 | 26 | .39 | 26 | 17-31 |
| 34 | CO1 Asbury | 86 | 127 | 9 | 22 | 9 | 59 | .84 | 45 | 29-71 |
| 35 | IL1 Lamb Inlets | 85 | 124 | 8 | 17 | 26 | 49 | .53 | 43 | 36-51 |
| 36 | MA1 Locust | 85 | 154 | 11 | 16 | 6 | 107 | .21 | 104 | 80-135 |
| 37 | NC1 #1081 | 84 | 324 | 6 | 27 | 66 | 39 | .60 | 33 | 29-17 |
| 38 | MA1 Jordan | 79 | 110 | 10 | 31 | 8 | 74 | .24 | 72 | - |
| 39 | DC1 Stedwick | 78 | 27 | 15 | 34 | 9 | 31 | .15 | 25 | 21-25 |

**Urban Open and Nonurban**

| | Site | Land Use % Open | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | Total Copper Mean | Total Copper COV | Total Copper Median | Total Copper 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CA1 Seaview | 150 | 633 | - | - | 12 | 59 | .31 | 55 | 46-65 |
| 2 | CO1 Rooney Gulch | 100 | 405 | 0 | 1 | 3 | 37 | 1.09 | 25 | 11-48 |
| 3 | NY1 Thornell | 100 | 28,410 | - | 4 | 0 | - | - | - | - |
| 4 | NY1 English Br | 98 | 6,749 | - | 1 | 0 | - | - | - | - |
| 5 | NY2 West Br | 97 | 5,338 | - | 1 | 0 | - | - | - | - |
| 6 | NY3 Thomas Cr | 91 | 17,728 | 1 | 11 | 0 | - | - | - | - |
| 7 | NY3 Teague Cr | 90 | 2,303 | - | 8 | 0 | - | - | - | - |
| 8 | NY1 Sherriff Lou | 90 | 557 | - | 7 | 0 | - | - | - | - |

**Mixed**

| | Site | Land Use % | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | Total Copper Mean | Total Copper COV | Total Copper Median | Total Copper 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | KS1 Naland | - | 36 | 1 | 68 | 9 | 48 | .38 | 45 | 16-57 |
| 2 | MD1 Hampden | - | 17 | 40 | 78 | 20 | 81 | .96 | 51 | 45-92 |
| 3 | IL1 Mattis N | - | 77 | 3 | 58 | 17 | 48 | .81 | 17 | 31-45 |
| 4 | MI1 Waverly | - | 30 | 11 | 69 | 16 | 15 | .50 | 13 | 10-16 |
| 5 | TN1 SC | - | 181 | 3 | 41 | 13 | 42 | 1.35 | 25 | 15-41 |
| 6 | WI1 Wood Ctr | - | 45 | 12 | 81 | 11 | - | - | - | - |
| 7 | MA1 Rt 9 | - | 118 | 7 | 23 | 7 | 112 | .49 | 100 | 71-141 |
| 8 | MA1 Lenox | - | 110 | 1 | 31 | 7 | 105 | .41 | 96 | 71-130 |
| 9 | MI1 Grand R 01 | - | 451 | 5 | 38 | 13 | 31 | .53 | 26 | 20-33 |
| 10 | MI3 Pitt AA-S | - | 2003 | 2 | 23 | 0 | - | - | - | - |
| 11 | NY2 Cedar | - | 76 | - | 5 | 0 | - | - | - | - |
| 12 | MA1 Anna | - | 601 | 9 | 12 | 5 | 54 | .51 | 46 | 30-71 |
| 13 | MI3 Pitt AA-N | - | 2811 | 7 | 26 | 0 | - | - | - | - |
| 14 | MI1 Grand N | - | 184 | 5 | 29 | 9 | 14 | .31 | 13 | 11-15 |
| 15 | MI3 Swift Run | - | 1203 | 2 | 4 | 0 | - | - | - | - |
| 16 | SD1 Meade | - | 2030 | - | - | 0 | - | - | - | - |
| 17 | CA1 Knox | - | 1542 | 12 | - | 17 | 95 | 1.14 | 65 | 44-96 |
| 18 | FL1 N. Jesuit | - | 30 | - | 13 | 15 | 7 | .61 | 5 | 5-8 |
| 19 | FL1 Wilder | - | 194 | - | 27 | 15 | 6 | .84 | 5 | 4-7 |
| 20 | CO1 North Ave | - | 69 | 9 | 51 | 12 | 71 | .82 | 54 | 42-74 |

**Commercial**

| | Site | Land Use % Comml | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | Total Copper Mean | Total Copper COV | Total Copper Median | Total Copper 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CO1 Villa Italia | 100 | 14 | 0 | 91 | 27 | 31 | .87 | 25 | 20-32 |
| 2 | NC1 1011 (CBD) | 100 | 23 | 0 | 49 | 61 | 70 | .54 | 61 | 52-60 |
| 3 | NY1 Southgate | 100 | 179 | 0 | 21 | 0 | - | - | - | - |
| 4 | WI1 Post Office | 100 | 12 | 2 | 100 | 0 | - | - | - | - |
| 5 | NH1 Pkg Lot | 100 | 3 | 0 | 95 | 11 | 106 | .13 | 101 | - |
| 6 | TN1 CBD | 100 | 26 | 0 | 99 | 15 | 42 | .60 | 36 | 28-41 |
| 7 | WI1 Rustler | 100 | 12 | 0 | - | 0 | - | - | - | - |
| 8 | KS1 11 Metcalf | 96 | 58 | - | 97 | 6 | 31 | .33 | 19 | 10-51 |
| 9 | IL1 Norma 2k | 93 | 48 | - | 65 | 12 | 11 | .37 | 10 | 8-13 |
| 10 | WI1 State Fair | 74 | 29 | 10 | 77 | 0 | - | - | - | - |

**Industrial**

| | Site | Land Use % Ind | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | Total Copper Mean | Total Copper COV | Total Copper Median | Total Copper 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | MA2 Addison | 100 | 18 | 0 | 19 | 0 | - | - | - | - |
| 2 | MI1 Indus Drain | 111 | 53 | 0 | 64 | 6 | 30 | .53 | 37 | [illegible] |
| 3 | KS1 Lenexa | 58 | 72 | - | 44 | 5 | 35 | .24 | 35 | 28-41 |
| 4 | MI1 Grace St. | 58 | 15 | 5 | 35 | 7 | 25 | .35 | 21 | 14-[illegible] |

# TABLE 6-9. SITE MEAN TOTAL LEAD EMCs (μg/ℓ)

| Residential | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Total lead | | | |
| | Site | Land Use % Res | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | Mean | COV | Median | 90% Confidence Limits |
| 1 | DC1 Big Dry Cr | 100 | 13 | 19 | 41 | 16 | 183 | .88 | 117 | 98-191 |
| 2 | CO1 Cherry | 100 | 51 | 24 | 18 | 14 | 194 | .92 | 143 | 99-207 |
| 3 | CO1 Glen Clarie | 100 | 167 | 14 | 24 | 16 | 292 | .87 | 210 | 151-292 |
| 4 | DC1 Dufief | 100 | 12 | - | - | 1 | - | - | - | - |
| 5 | DL1 Lakeridge | 100 | 68 | 21 | 33 | 18 | 227 | .54 | 201 | 164-245 |
| 6 | DC1 Stratton | 100 | 8 | - | - | 0 | - | - | - | - |
| 7 | IL1 John N | 100 | 94 | 18 | 19 | 16 | 717 | .71 | 191 | 158-211 |
| 8 | KS1 Overton | 100 | 58 | 8 | 18 | 11 | 118 | .19 | 128 | 104-157 |
| 9 | MA2 Hemlock | 100 | 55 | 5 | 16 | 0 | - | - | - | - |
| 10 | MD1 Rolling Hill | 100 | 14 | 30 | 51 | 19 | 2345 | 4.53 | 592 | 295-1188 |
| 11 | MD1 Homeland | 100 | 21 | 9 | 29 | 19 | 76 | .48 | 69 | 56-86 |
| 12 | MD1 Mt Wash | 100 | 17 | 12 | 29 | 20 | 86 | .48 | 77 | 65-92 |
| 13 | MD1 Res Mill | 100 | 10 | 55 | 76 | 17 | 461 | 1.86 | 218 | 119-399 |
| 14 | NH1 Carll's P | 100 | 71 | 13 | 20 | 0 | - | - | - | - |
| 15 | NY1 Unqua | 100 | - | - | - | 8 | 88 | 1.16 | 52 | 26-103 |
| 16 | MI1 Grassino | 100 | 166 | 5 | 22 | 31 | 34 | .77 | 27 | 19-38 |
| 17 | NY3 E. Roch. | 100 | 146 | 18 | 38 | 8 | 191 | .89 | 144 | 86-240 |
| 18 | TX1 Rollingwood | 100 | 60 | 3 | 21 | 0 | - | - | - | - |
| 19 | WA1 Surrey | 100 | 95 | 9 | 29 | 128 | 152 | .51 | 136 | 126-146 |
| 20 | WI1 Burbank | 100 | 63 | 15 | 51 | 44 | 95 | .72 | 77 | 65-91 |
| 21 | WI1 Hastings | 100 | 33 | 17 | 51 | 15 | 108 | .67 | 90 | 75-107 |
| 22 | IL1 Young Apts | 100 | 9 | - | 6 | 12 | 36 | 1.03 | 51 | 14-82 |
| 23 | TX1 Hart | 99 | 178 | 9 | 40 | 0 | - | - | - | - |
| 24 | WI1 Lincoln | 91 | 16 | 18 | 57 | 22 | 303 | 1.39 | 200 | 141-280 |
| 25 | TN1 42 | 96 | 89 | 4 | 13 | 11 | 111 | .41 | 123 | 99-151 |
| 26 | DC1 Westleigh | 97 | 41 | 1 | 21 | 5 | 186 | .37 | 184 | 157-216 |
| 27 | KS1 IL - 52nd | 92 | 61 | - | 37 | 1 | - | - | - | - |
| 28 | IL1 John S. | 91 | 39 | 18 | 18 | 13 | 217 | .80 | 169 | 138-208 |
| 29 | TN1 41 | 91 | 69 | 11 | 11 | 11 | 440 | .61 | 776 | 277-511 |
| 30 | WA1 Lake Hills | 91 | 102 | 17 | 32 | 126 | 192 | .67 | 159 | 140-174 |
| 31 | IL1 Mallis S. | 98 | 28 | 22 | 17 | 37 | 595 | 1.12 | 196 | 308-508 |
| 32 | IL1 Charter Rdg | 89 | 92 | - | 16 | 12 | 49 | 1.60 | 26 | 14-47 |
| 33 | DC1 Fairidge | 68 | 19 | - | 14 | 1 | - | - | - | - |
| 34 | LB1 Asbury | 86 | 127 | 9 | 22 | 9 | 431 | .12 | 151 | 251-524 |
| 35 | IL2 Lamb Inlets | 85 | 524 | 6 | 17 | 24 | 122 | 1.01 | 217 | 169-304 |
| 36 | MA1 Locust | 85 | 154 | 11 | 14 | 6 | 213 | .67 | 225 | 116-171 |
| 37 | MI1 #1023 | 84 | 129 | 6 | 27 | 66 | 254 | .98 | 182 | 151-215 |
| 38 | MA1 Jordan | 79 | 110 | 10 | 21 | 9 | 168 | .12 | 166 | 112-194 |
| 39 | DC1 Stedwick | 78 | 27 | 15 | 34 | 11 | 141 | .41 | 110 | 105-161 |

| Urban Open and Nonurban | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Total lead | | | |
| | Site | Land Use % Open | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | Mean | COV | Median | 90% Confidence Limits |
| 1 | FN1 Sanivew | 100 | 631 | - | - | 7 | 214 | .54 | 159 | 91-279 |
| 2 | CO1 Rooney Gulch | 100 | 455 | 1 | 1 | 7 | 52 | .51 | 39 | 26-69 |
| 3 | NY3 Thornell | 100 | 25,416 | - | 4 | 10 | 12 | .42 | 11 | 9-14 |
| 4 | MI2 English Br | 98 | 5,248 | - | 1 | 21 | 4 | .60 | 8 | 6-10 |
| 5 | MI2 West Br | 97 | 1,278 | - | 1 | 25 | 78 | 1.40 | 22 | 15-31 |
| 6 | MI3 Thomas Cr | 91 | 13,126 | 1 | 11 | 22 | 75 | 1.65 | 18 | 10-31 |
| 7 | MI3 Traver Cr | 90 | 2,303 | - | 6 | 0 | - | - | - | - |
| 8 | MI2 Sheriff Duck | 90 | 557 | - | 7 | 17 | 132 | 1.09 | 91 | 73-117 |

| Mixed | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Total lead | | | |
| | Site | Land Use 1 | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | Mean | COV | Median | 90% Confidence Limits |
| 1 | KS1 Noland | - | 36 | 1 | 68 | 9 | 164 | .49 | 147 | 110-196 |
| 2 | MD1 Hampden | - | 17 | 40 | 72 | 20 | 227 | .82 | 176 | 131-212 |
| 3 | IL1 Mattis N | - | 17 | 3 | 58 | 41 | 554 | 1.06 | 180 | 103-478 |
| 4 | MI1 Waverly | - | 30 | 11 | 68 | 24 | 311 | 1.09 | 75 | 55-102 |
| 5 | TN1 SC | - | 187 | 1 | 43 | 13 | 237 | .31 | 227 | 195-214 |
| 6 | WI1 Wood Ctr | - | 95 | 12 | 81 | 45 | 582 | .94 | 424 | 348-517 |
| 7 | MA1 Rt 9 | - | 338 | 7 | 71 | 7 | 419 | 1.02 | 167 | 165-571 |
| 8 | MA1 Convent | - | 100 | 1 | 13 | 7 | 196 | .94 | 143 | 80-257 |
| 9 | MI1 Grand R Ot | - | 451 | 5 | 38 | 18 | 122 | .90 | 91 | 66-125 |
| 10 | MI3 Pitt AA-S | - | 2001 | 2 | 21 | 6 | 21 | 1.63 | 11 | 4-28 |
| 11 | NY2 Cedar | - | 76 | - | 5 | 28 | 75 | 1.25 | 47 | 34-69 |
| 12 | MA1 Anna | - | 601 | 9 | 12 | 4 | - | - | - | - |
| 13 | MI3 Pitt AA-M | - | 2871 | 7 | 26 | 5 | 61 | .71 | 50 | 27-92 |
| 14 | MI1 Grace A | - | 164 | 5 | 28 | 18 | 170 | 1.79 | 99 | 65-151 |
| 15 | MI3 Swift Run | - | 1207 | 2 | 4 | 4 | - | - | - | - |
| 16 | SO1 Meade | - | 2030 | - | - | 24 | 381 | 1.13 | 254 | 165-390 |
| 17 | CA1 Knox | - | 1542 | 12 | - | 22 | 495 | .99 | 351 | 259-475 |
| 18 | FL1 N. Jesuit | - | 10 | - | 13 | 15 | 56 | 1.22 | 35 | 23-54 |
| 19 | FL1 Wilder | - | 194 | - | 97 | 15 | 86 | .85 | 55 | 46-91 |
| 20 | CO1 North Ave | - | 69 | 9 | 50 | 11 | 158 | .32 | 278 | 226-343 |

| Commercial | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Total lead | | | |
| | Site | Land Use % Coml | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | Mean | COV | Median | 90% Confidence Limits |
| 1 | CO1 Villa Italia | 100 | 74 | 6 | 91 | 27 | 262 | 1.21 | 187 | 172-224 |
| 2 | MD1 1011 (CBD) | 100 | 21 | 0 | 69 | 61 | 383 | .81 | 296 | 254-349 |
| 3 | NY3 Southgate | 100 | 179 | 0 | 21 | 13 | 47 | .58 | 42 | 31-53 |
| 4 | WI1 Post Office | 100 | 13 | 2 | 100 | 59 | 191 | .93 | 145 | 126-173 |
| 5 | MH1 Pkg Lot | 100 | 1 | 0 | 90 | 11 | 208 | .93 | 152 | 121-197 |
| 6 | TN1 CBD | 100 | 26 | 5 | 99 | 15 | 158 | .52 | 140 | 112-175 |
| 7 | WI1 Rustler | 100 | 12 | 0 | - | 44 | 123 | .73 | 98 | 83-115 |
| 8 | KS1 IC Metcalf | 96 | 58 | - | 97 | 7 | - | - | - | - |
| 9 | FL1 Palma Ck | 91 | 47 | - | 45 | 12 | 46 | 1.01 | 37 | 21-46 |
| 10 | WI1 State Fair | 74 | 29 | 10 | 37 | 27 | 409 | .86 | 310 | 243-396 |

| Industrial | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Total lead | | | |
| | Site | Land Use % Ind | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | Mean | COV | Median | 90% Confidence Limits |
| 1 | MA2 Addison | 100 | 18 | 0 | 69 | 0 | - | - | - | - |
| 2 | MI3 Indus Drain | 100 | 63 | 0 | 64 | 13 | 116 | .77 | 93 | 65-121 |
| 3 | KS1 Lenexa | 56 | 72 | - | 44 | 6 | - | - | - | - |
| 4 | MI1 Grace S. | 52 | 15 | 5 | 39 | 13 | 116 | .76 | 92 | 66-128 |

# TABLE 6-10. SITE MEAN TOTAL ZINC EMCs (µg/ℓ)

**Residential**

| | Site | Land Use % Res | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | Total Zinc Mean | COV | Median | 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CO1 Big Dry Cr. | 100 | 37 | 19 | 41 | 15 | 194 | .80 | 151 | 110-208 |
| 2 | CO1 Cherry | 100 | 57 | 24 | 38 | 19 | 195 | .61 | 155 | 126-217 |
| 3 | CO1 116 Claude | 100 | 167 | 14 | 24 | 13 | 195 | .66 | 158 | 171-206 |
| 4 | DC1 Dufief | 100 | 22 | - | - | 8 | 156 | .26 | 151 | 137-179 |
| 5 | DC1 Lakeridge | 100 | 58 | 21 | 31 | 48 | 129 | .70 | 106 | 91-171 |
| 6 | DC1 Stratton | 100 | 5 | - | - | 28 | 84 | .47 | 76 | 66-88 |
| 7 | IL1 John M | 100 | 34 | 18 | 19 | 0 | - | - | - | - |
| 8 | KS1 Overland | 100 | 58 | 8 | 38 | 33 | 841 | .97 | 596 | 399-891 |
| 9 | MA2 Fenland | 100 | 50 | 5 | 16 | 0 | - | - | - | - |
| 10 | MD1 Gallion Hill | 100 | 14 | 10 | 52 | 19 | 1388 | 2.21 | 573 | 117-971 |
| 11 | MD1 Homeland | 100 | 21 | [illegible] | 29 | 33 | 120 | .15 | 113 | 96-114 |
| 12 | MD1 Mt Wash | 100 | 17 | 12 | 29 | 29 | 92 | .54 | 81 | 67-98 |
| 13 | MD1 Res. Hill | 100 | 10 | 55 | 75 | 11 | 523 | 1.20 | 140 | 211-542 |
| 14 | NY1 Carll's C | 100 | 73 | 11 | 20 | 0 | - | - | - | - |
| 15 | NY1 Unqua | 100 | - | - | - | 0 | - | - | - | - |
| 16 | NY2 Cranston | 100 | 160 | 5 | 22 | 9 | 415 | .88 | 117 | 195-499 |
| 17 | NY3 E. Rock | 100 | 346 | 18 | 39 | 8 | 988 | 1.10 | 127 | 180-594 |
| 18 | TX1 Hillingwells | 100 | 90 | 7 | 21 | 0 | - | - | - | - |
| 19 | WA1 Surrey | 100 | 91 | 9 | 29 | 118 | 174 | .82 | 114 | 107-121 |
| 20 | WI1 Burbank | 100 | 63 | 15 | 50 | 18 | 106 | 1.14 | 63 | 42-95 |
| 21 | WI1 Hastings | 100 | 33 | 17 | 51 | 21 | 106 | 1.20 | 69 | 49-99 |
| 22 | TX1 Young Apts | 100 | 9 | - | 6 | 12 | 60 | .45 | 55 | 44-69 |
| 23 | TX1 Hart | 99 | 276 | 0 | 40 | 13 | - | - | - | - |
| 24 | WI1 Lincoln | 97 | 36 | 18 | 57 | 8 | - | - | - | - |
| 25 | TN1 RE | 96 | 89 | 4 | 33 | 11 | 91 | .52 | 81 | 61-109 |
| 26 | OR1 Wessleign | 93 | 41 | 1 | 21 | 14 | 67 | .96 | 48 | 38-61 |
| 27 | KS1 IC - 92nd | 92 | 63 | - | 17 | 3 | - | - | - | - |
| 28 | IL1 John S. | 91 | 39 | 18 | 18 | 1 | - | - | - | - |
| 29 | SM1 91 | 91 | 69 | 11 | 11 | 11 | 412 | .59 | 754 | 261-477 |
| 30 | WA1 Lake Mills | 91 | 102 | 12 | 17 | 126 | 120 | .51 | 107 | 99-115 |
| 31 | IL1 Maltis S. | 90 | 38 | 22 | 17 | 0 | - | - | - | - |
| 32 | FL1 Charter Hog | 89 | 42 | - | 16 | 12 | 54 | 1.02 | 78 | 35-59 |
| 33 | OR1 Fairidge | 88 | 19 | - | 14 | 44 | 86 | .52 | 76 | 67-86 |
| 34 | OR1 Asbury | 86 | 127 | 9 | 22 | 9 | 149 | .61 | 295 | 206-427 |
| 35 | IL2 Cimb Inlets | 85 | 524 | 8 | 12 | 27 | 210 | .69 | 189 | 154-212 |
| 36 | MA1 Locust | 85 | 154 | 11 | 16 | 6 | 247 | .11 | 216 | 184-301 |
| 37 | NC1 #1023 | 84 | 324 | 6 | 27 | 66 | 178 | .81 | 118 | 139-160 |
| 38 | MA1 Jordan | 79 | 110 | 10 | 21 | 9 | 218 | .28 | 210 | 177-249 |
| 39 | OC1 Stedwick | 78 | 27 | 15 | 14 | 45 | 91 | .70 | 75 | 64-86 |

**Urban Open and Nonurban**

| | Site | Land Use % Open | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | Total Zinc Mean | COV | Median | 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CO1 Seaview | 100 | 633 | - | - | 17 | 190 | .69 | 160 | 125-205 |
| 2 | CO1 Rooney Gulch | 100 | 405 | 0 | 1 | 7 | 115 | .56 | 91 | 61-136 |
| 3 | NY3 Thorndl | 100 | 25,415 | - | 4 | 9 | 292 | 2.39 | 306 | 110-720 |
| 4 | NY2 English Pk | 99 | 5,208 | - | 1 | 0 | - | - | - | - |
| 5 | NY1 Bet Br | 97 | 5,138 | - | 1 | 10 | - | - | - | - |
| 6 | NY3 Thomas Cr | 91 | 17,724 | 1 | 11 | 9 | 1063 | 3.24 | 327 | 131-839 |
| 7 | NY3 Traver Cr | 90 | 2,707 | - | 6 | 2 | - | - | - | - |
| 8 | NY2 Sheriff Pool | 89 | 552 | - | 7 | 9 | - | - | - | - |

**Mixed**

| | Site | Land Use % | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | Total Zinc Mean | COV | Median | 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | KS1 Holland | - | 35 | 3 | 68 | 9 | [illegible] | 1.19 | 525 | 242-940 |
| 2 | MD1 Hampden | - | 11 | 40 | 72 | 17 | 319 | .75 | 112 | 276-140 |
| 3 | IL1 Mottis N | - | 17 | 3 | 98 | 0 | - | - | - | - |
| 4 | MI1 Waverly | - | 30 | 11 | 58 | 17 | 121 | .95 | 110 | 92-13[illegible] |
| 5 | TN1 SC | - | 197 | 3 | 43 | 12 | 146 | .40 | 134 | 114-16[illegible] |
| 6 | WI1 Wogo Ctr | - | 45 | 17 | 81 | 27 | 475 | 1.21 | 303 | [illegible] |
| 7 | MA1 Ply | - | 738 | [illegible] | [illegible] | [illegible] | 244 | [illegible] | 225 | 165-304 |
| 8 | MA1 Convent | - | 130 | 1 | 33 | [illegible] | 207 | .69 | 174 | 135-270 |
| 9 | MI1 Grand R ll | - | 451 | 1 | 38 | 14 | 245 | [illegible] | [illegible] | 186-[illegible] |
| 10 | WI1 Pitt AA-S | - | 2901 | 2 | 21 | 4 | - | - | - | - |
| 11 | NY2 Cedar | - | 76 | - | 5 | 0 | - | - | - | - |
| 12 | MA1 Anna | - | 601 | 9 | 12 | 5 | 176 | 1.50 | 99 | [illegible] |
| 13 | MI3 Pitt AA-h | - | 2873 | 7 | 26 | 4 | - | - | - | - |
| 14 | MI1 Grace M | - | 154 | 5 | 78 | 9 | 149 | .35 | 140 | [illegible] |
| 15 | MI3 Swift Run | - | 1207 | 2 | 4 | [illegible] | - | - | - | - |
| 16 | SD1 Meade | - | 2910 | - | - | 0 | - | - | - | - |
| 17 | CA1 Knox | - | 1542 | 12 | - | 21 | 202 | .55 | 31 | [illegible] |
| 19 | FL1 N. Jesuit | - | 30 | - | 11 | 15 | 94 | .68 | 79 | 69-101 |
| 19 | FL1 Wilder | - | 194 | - | 97 | 15 | 51 | .95 | 37 | 36-5[illegible] |
| 20 | CO1 North Ave | - | 69 | 9 | 50 | 13 | 541 | .82 | 401 | 241-[illegible] |

**Commercial**

| | Site | Land Use % Com | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | Total Zinc Mean | COV | Median | 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CO1 Villa Italia | 100 | 74 | 0 | 41 | 27 | 120 | .82 | 297 | 195-313 |
| 2 | NC1 1911 (C90) | 100 | 21 | 0 | 19 | 60 | 521 | .51 | 478 | 428-526 |
| 3 | MN1 Southdale | 100 | 179 | 2 | 21 | 9 | 1438 | 1.56 | 517 | 214-1247 |
| 4 | WI1 Post Office | 100 | 12 | 0 | 100 | 32 | 145 | 1.16 | 44 | 71-124 |
| 5 | MN1 Plg Lal | 100 | 1 | 0 | 36 | 31 | 511 | .65 | 410 | 361-517 |
| 6 | TN1 CBD | 100 | 29 | 0 | 99 | 15 | 115 | .41 | 289 | 240-349 |
| 7 | WI1 Rustler | 100 | 12 | 0 | - | 19 | 156 | .75 | 175 | 96-161 |
| 8 | KS1 IC Metcalf | 96 | 58 | - | 97 | 7 | 465 | .79 | 168 | 272-811 |
| 9 | FL1 Norma Pk | 91 | 47 | - | 45 | 12 | 17 | .88 | 29 | 19-41 |
| 10 | WI1 State Fair | 74 | 29 | 10 | 77 | 7 | 380 | .65 | 234 | 150-163 |

**Industrial**

| | Site | Land Use % Ind | Area (A) | Pop. Den (#/A) | % IMP. | No. of OBS | Total Zinc Mean | COV | Median | 90% Confidence Limits |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | MA2 Addison | 100 | 10 | 0 | 69 | 8 | - | - | - | - |
| 2 | MI1 Indus Drain | 100 | 63 | 0 | 64 | 7 | 244 | .42 | 725 | 167-3[illegible] |
| 3 | KS1 Lenexa | 56 | 72 | - | 44 | 6 | 2721 | 2.79 | 701 | 317-28[illegible] |
| 4 | MI1 Grace S. | 52 | 75 | 5 | 39 | 7 | 233 | .54 | 196 | 175-264 |

* All observations below detection limit.

These tables (one for each pollutant) list each of the appropriate sites in the data base, grouped according to general land use category. Some pertinent site characteristics are identified: drainage area, population density, and the percentage of the total area covered by impervious surfaces. The number of monitored storms at each site is tabulated. Urban runoff quality is summarized by the mean and median EMC for all storms monitored at the site, the storm-to-storm variability of EMC's (defined by the coefficient of variation), and the 90 percent confidence limits for the site median EMC.

Transferability of Data

The urban runoff loading site EMC data were carefully examined in an effort to determine whether specific groupings of results would suggest the presence of consistent patterns of similarities and/or differences that could be used to support estimates of urban runoff characteristics at unmonitored locations and sites.

Variability of EMCs at a Site. Inspection and analysis of the individual site coefficient of variation entries in Tables 6-1 through 6-10 shows that with very few exceptions (usually associated with constituents that were monitored in fewer than 10 storm events) the coefficients of variation fall in the range of 0.5 to 1.0. This applies to all constituents except TSS, for which the range in coefficients of variation is more like 1 to 2.

The frequency of occurrence of any EMC of interest can be estimated readily from the coefficient of variation by using the procedures outlined in Chapter 5. Thus, for TSS, 90 percent of the individual storm events at a given site will have EMCs that do not exceed a value of roughly 3 to 5 times the median EMC value for that site. For the other constituents, 90 percent of the individual storm events at a site will have EMCs less than about 2 to 3 times the median EMC value for that site. More refined estimates and values for other exceedance probabilities can be readily computed using the relationships presented in Chapter 5.

Effect of Geographic Location. Figures 6-4 through 6-13 indicate the range of median EMC's at individual sites, grouped by project. The land use category of the site is indicated by the letter R for residential, M for mixed, and C for commercial/industrial, and the plotting position is the median value as given by the data in Tables 6-1 through 6-10. The ends of the bars for each project are the highest and lowest 90 percent confidence limits for site median EMCs at the project for the constituent in question. Inspection of Figures 6-4 through 6-13 indicates that, for any given constituent, each project can be put into one of three rather general categories: (1) low EMCs and tightly grouped; (2) average characteristics; and (3) wide range and high EMCs. Using the numbers 1, 2, and 3 as shorthand, project categories for each constituent are summarized in Table 6-11. Although no site is category consistent for all constituents, WASHCOG (DC1), Tampa (FL1), Lansing (MI1), and Ann Arbor (MI3) tend to have lower and more tightly grouped EMCs than the others while Kansas City (KS1), Lake Quinsigamond (MA1), and Baltimore (MD1) tend to have a wider range and higher EMCs than the others. Thus we can conclude that some projects represented in the database appear, from the monitoring sites selected, to tend towards somewhat higher or lower EMC median values and ranges than the bulk of the projects. However, there are no distinct geographical patterns revealed.

83-2061

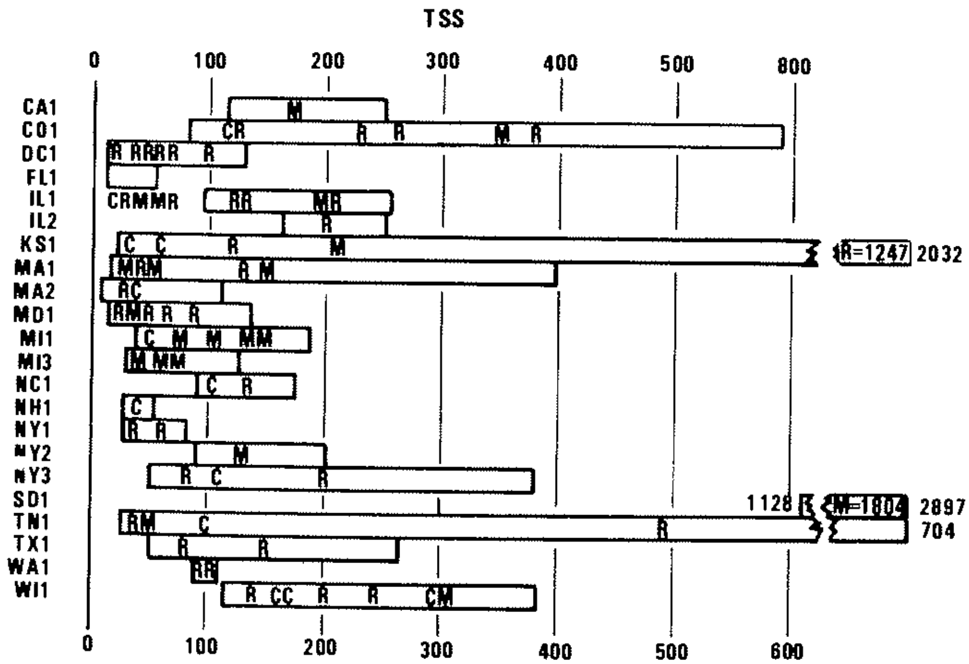


Figure 6-4. Range of TSS EMC Medians (mg/l) by Project

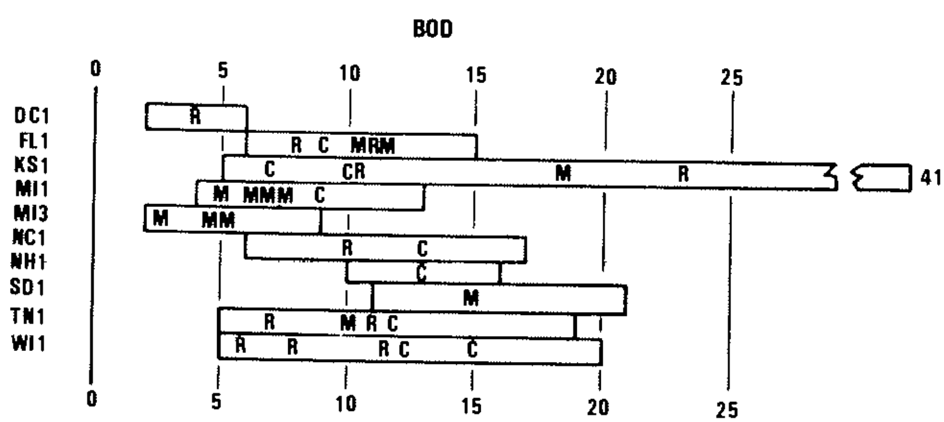


Figure 6-5. Range of BOD EMC Medians (mg/l) by Project

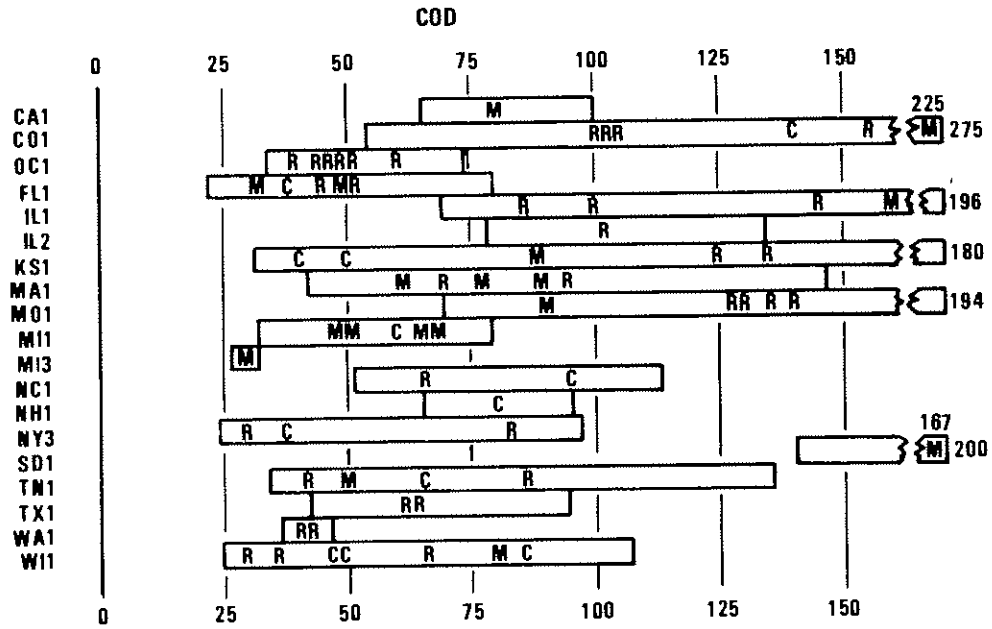


Figure 6-6. Range of COD EMC Medians (mg/l) by Project

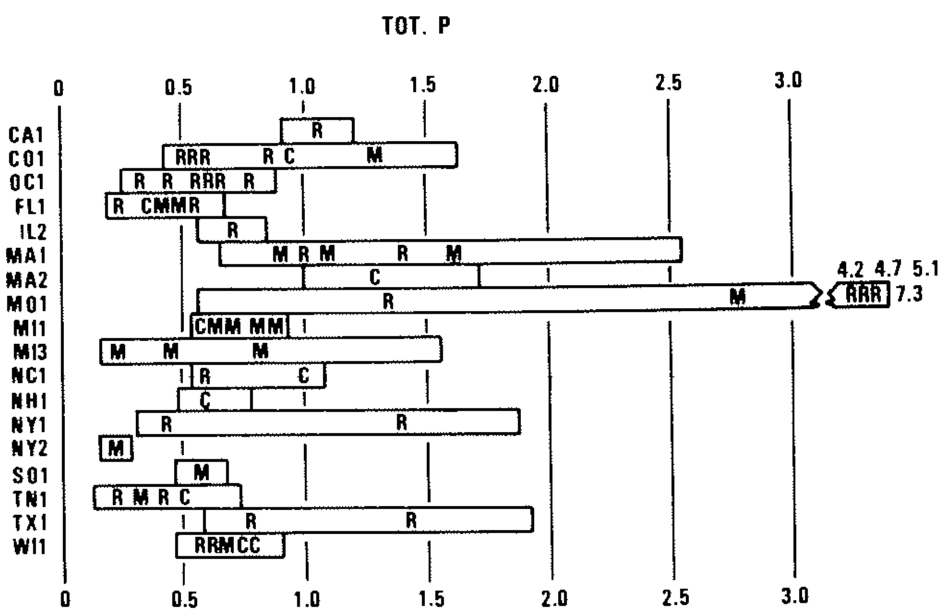


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Figure 6-7. Range of Total P EMC Medians (mg/l) by Project

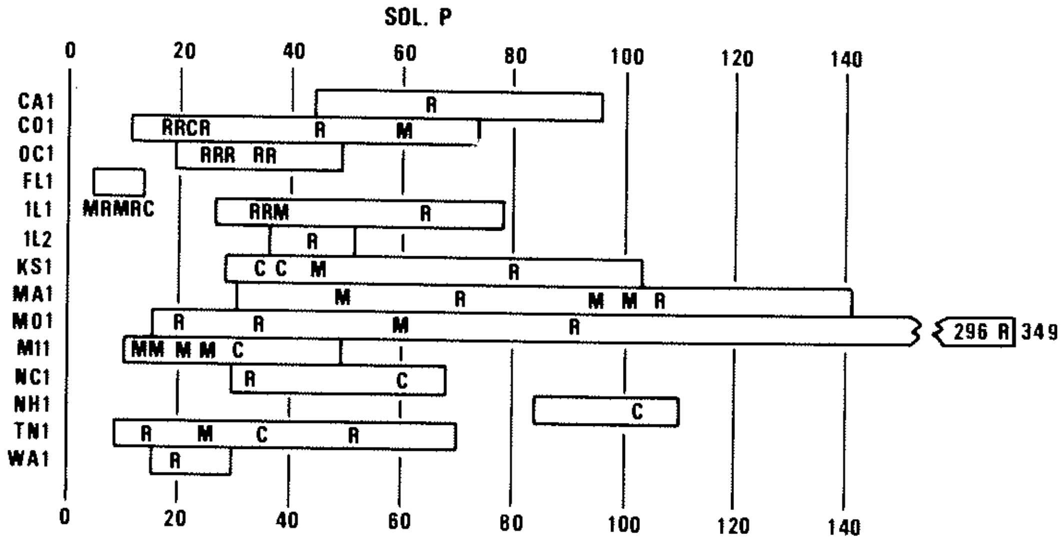



Figure 6-8. Range of Soluble P EMC Medians (mg/l) by Project

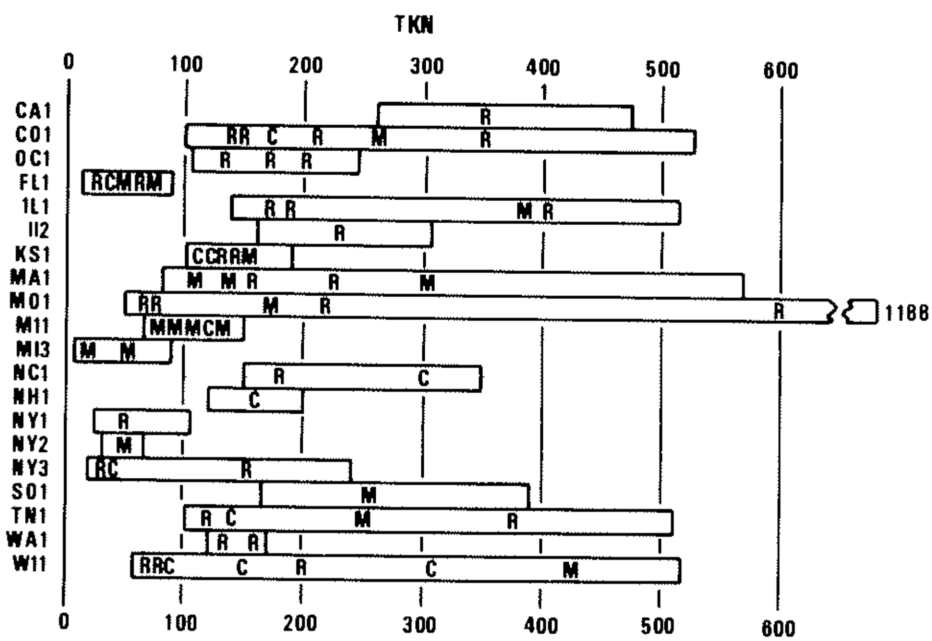



Figure 6-9. Range of TKN EMC Medians (mg/l) by Project

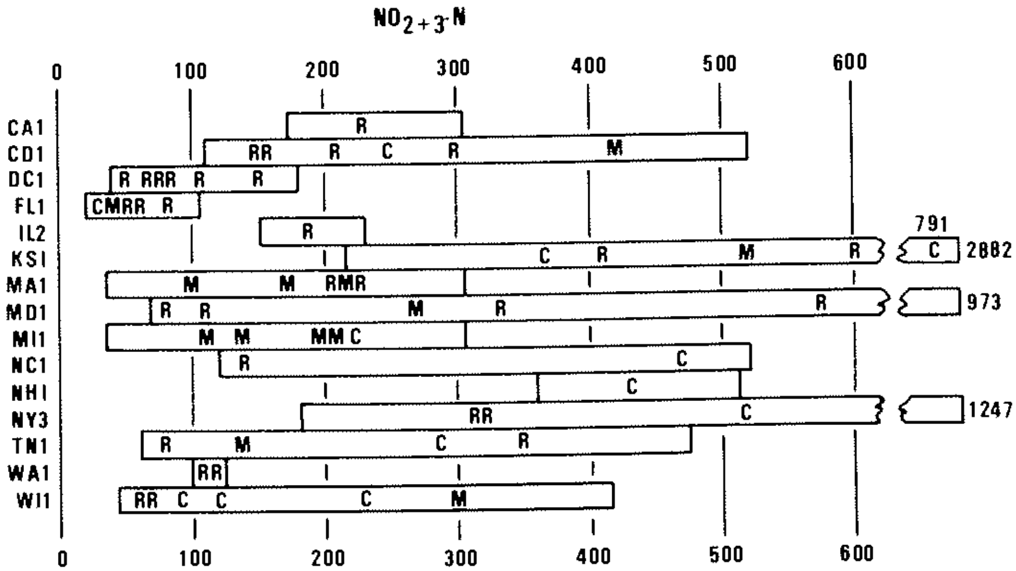



Figure 6-10. Range of $NO_{2+3}$-N EMC Medians (mg/l) by Project

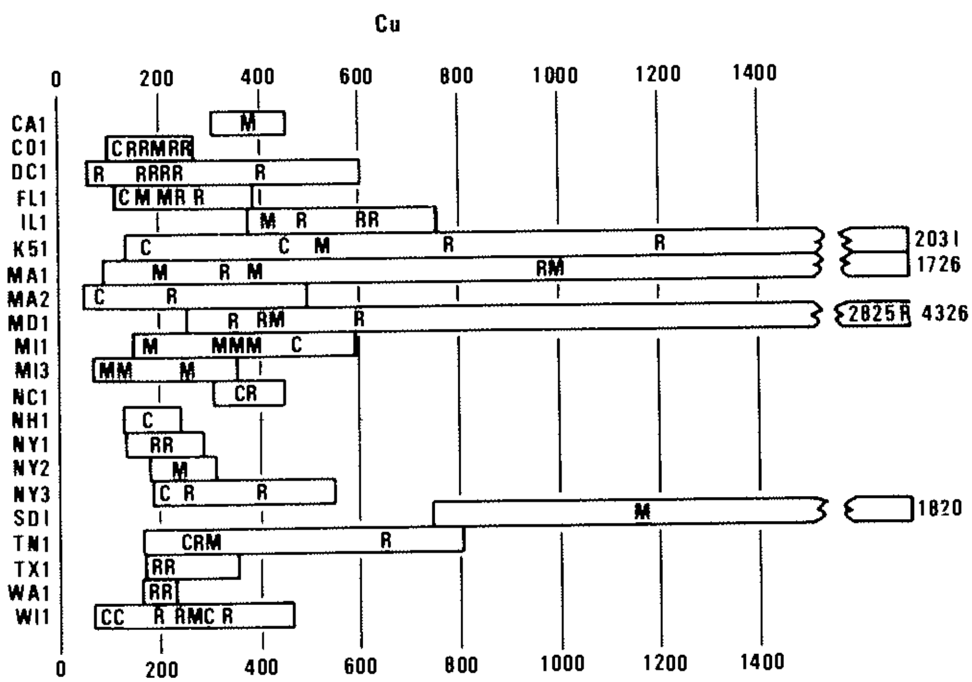



Figure 6-11. Range of Total Cu EMC Medians (µg/l) by Project

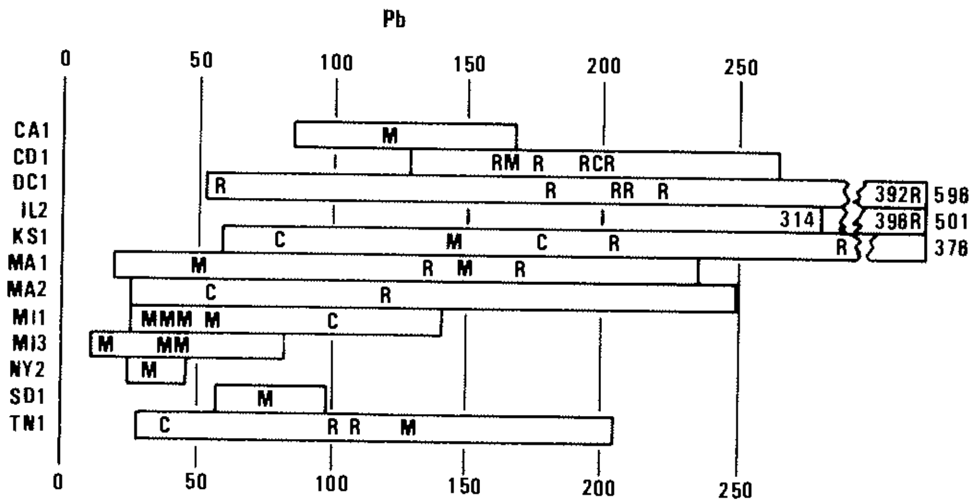



Figure 6-12. Range of Total Pb EMC Medians (μg/l) by Project

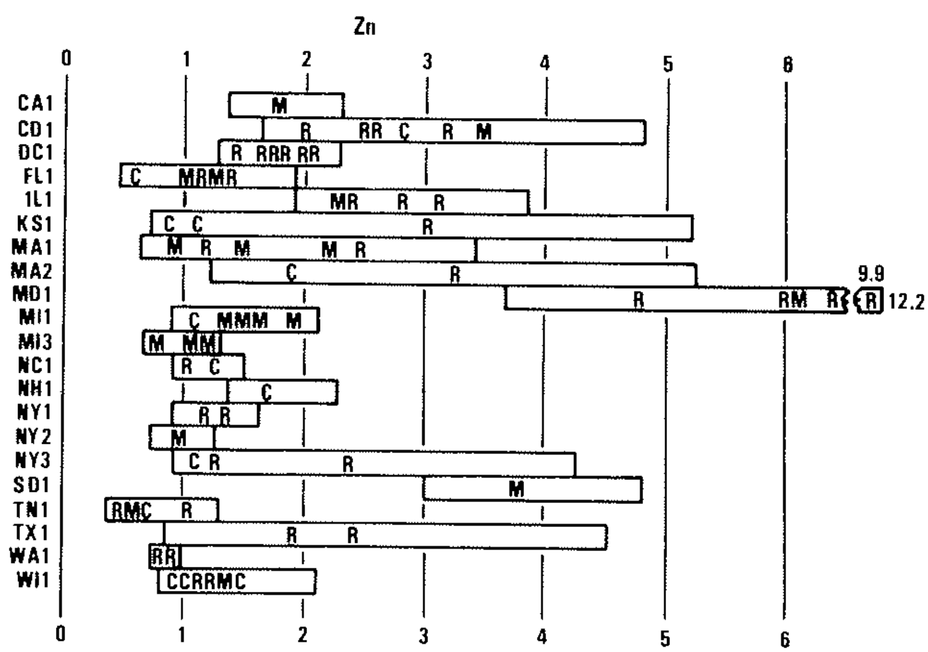


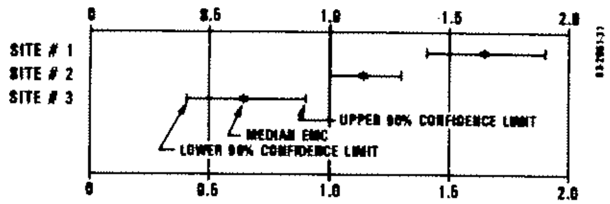

Figure 6-13. Range of Total Zn EMC Medians (μg/l) by Project

TABLE 6-11. PROJECT CATEGORY SUMMARIZED BY CONSTITUENT

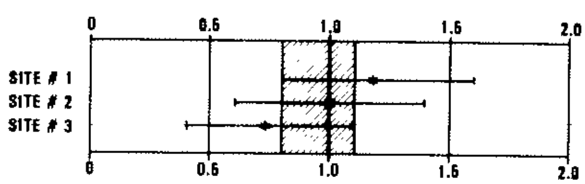
| | CO1 | DC1 | FL1 | IL1 | KS1 | MA1 | MD1 | MI1 | MI3 | NY3 | TN1 | WI1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TSS | 3 | 1 | 1 | 2 | 3 | 3 | 1 | 1 | 1 | 2 | 3 | 2 |
| BOD | - | - | 2 | - | 3 | - | - | 2 | 1 | - | 2 | 2 |
| COD | 3 | 1 | 1 | 3 | 3 | 2 | 3 | 1 | - | 1 | 2 | 2 |
| Tot. P. | 1 | 2 | 1 | 2 | 3 | 3 | 3 | 2 | 1 | 2 | 2 | 2 |
| Sol. P. | 2 | 3 | - | - | 3 | 2 | - | 2 | 1 | - | 2 | - |
| TKN | 2 | 1 | 1 | 2 | 2 | 2 | 3 | 1 | 1 | 2 | 1 | 1 |
| $NO_{2+3}$-N | 2 | 1 | 1 | - | - | 3 | 3 | 1 | 2 | - | 1 | 1 |
| Tot. Cu | 2 | 1 | 1 | 2 | 2 | 3 | 3 | 1 | - | - | 2 | - |
| Tot. b | 2 | 1 | 1 | 2 | 1 | 2 | 3 | 1 | - | 1 | 2 | 2 |
| Tot. Zn | 2 | 1 | 1 | - | 3 | 2 | 3 | 2 | - | 3 | 2 | 2 |

It must also be realized that had any particular project monitored other local sites (or additional sites) its categorization could well change. This can be seen qualitatively by perusing Figures 6-4 through 6-13 and mentally dropping the highest or lowest site from each grouping. Although some locations, such as Tampa, will undoubtably and appropriately be influenced by the relatively low EMCs and tight groupings found there in estimating probable values for other urban sites in the area, there is little to warrant attributing similar characteristics to other locations in the same geographical region. For the other locations it would appear that individual site differences eclipse any possible geographic ones.

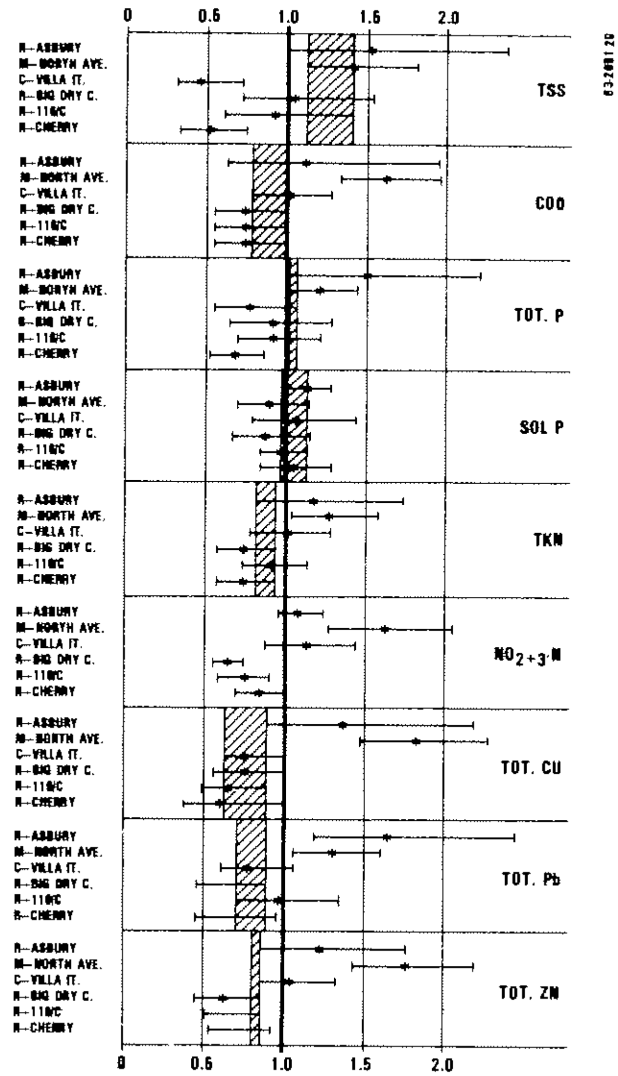
Effect of Land Use Category. The data in Tables 6-1 through 6-10 were presented by land use category; residential, mixed, commercial, industrial, and open/non-urban. The question to be addressed here is the extent to which such site categorization can be used to assist in predicting EMC parameters for unmonitored sites. Two approaches were used. In the first, the site data for each project with more than three sites were normalized by dividing the site median and its upper and lower 90 percent confidence limits by the average project median value for the constituent in question. This procedure simply allows all constituents to be viewed on a common scale that is centered at unity. An example of the result is given in Figure 6-14. A legend is provided in Figure 6-14(a) showing the lower 90 percent confidence limit, the upper 90 percent confidence limit, and the location of the point estimate of the median within this confidence interval for a hypothetical constituent. Sites that fall to the right of the unity line have higher EMCs than average for this location, while sites that fall to the left of the unity line have lower EMCs than average. Thus, the interpretation is that for this location, Site #1 is the "dirtiest" (has the highest EMC value), Site #3 is the "cleanest", and Site #2 is in between, being somewhat "dirtier" than average. Since the 90 percent confidence limits for these three sites no not overlap, we know that this difference is statistically significant.




(a) Significantly Different Sites




(b) Sites with No Significant Difference




(c) EMC Data from Denver (CO1)

Figure 6-14. Range of Normalized EMC Medians at Denver (CO1)

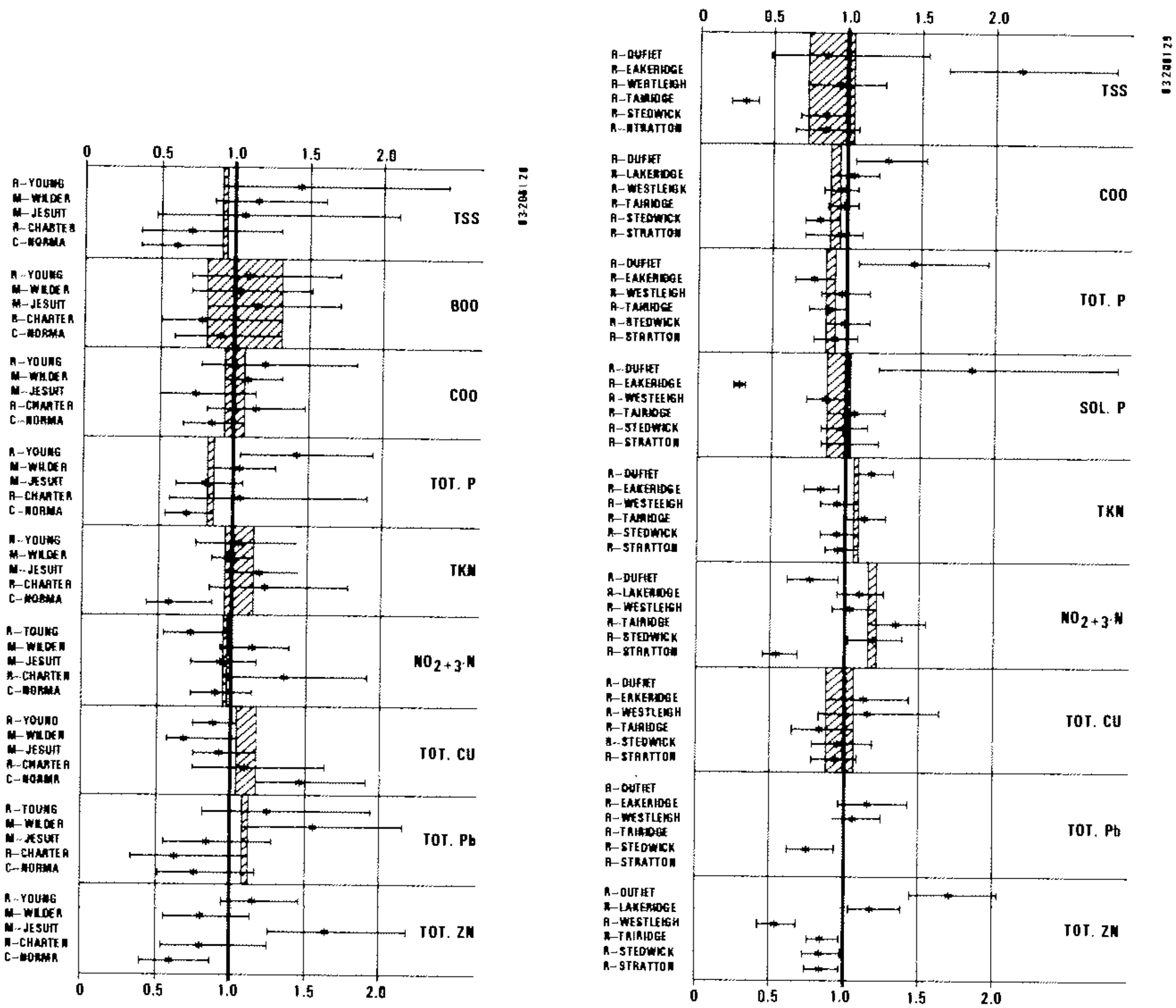
The actual data for the Denver (CO1) project are presented in Figure 6-14(c). With the exception of nitrate + nitrite, there is little to no statistically significant difference among the majority of the sites for each constituent examined. The lack of consistency among the sites over the various constituents is apparent. One can observe that the Cherry site (residential) tends to plot at the lowest position for all constituents, suggesting that it is the "cleanest," the Asbury site (also residential) tends to plot at the highest position, suggesting that it is the "dirtiest." The Big Dry Cottonwood site, which is also residential, tends to fall between these two. Careful examination of other site data does not provide any evidence to explain this difference in response for sites in the same land use category at the same location. Thus, based on the information presented in Figure 6-14(c), one is forced to conclude that land use category does not provide a useful basis for predicting differences in site EMC values, at least for this project.

When the foregoing type of analysis was applied to the other applicable NURP projects, the results were the same. As another example, the range of normalized EMC medians at Tampa (FL1) and WASHCOG (DC1) are shown in Figure 6-15. These are essentially similar to the Denver results just discussed.

The WASHCOG data presented in Figure 6-15(b) suggest that there is little consistent difference among residential land use sites at that project. The data from Champaign/Urbana (IL1) presented in Figure 6-16 suggest just the opposite. As a part of this project's experimental design, two site pairs were selected. The sites of each pair were expected to respond in a similar fashion. That they do and that the responses of the two pairs are different from each other for most constituents is apparent in Figure 6-16. However, there is no consistency in the pair responses. For example, the Mattis pair has significantly higher EMC values for TSS, COD, and Total Pb, while the John Pair is higher in Total P. The residential land use category for these sites provides no explanation of these differences in response.

Based upon the foregoing approach, we can conclude that, while there can be differences in the responses of different sites at a given location, significant differences do not appear to be widespread, and where they occur, the site land use category is virtually useless in trying to understand or predict them.

The second approach to examining the effect of land use category on the EMC parameters of a site makes use of the observation, discussed earlier, that geographic location has no discernible effect on site response. Since site to site variability was shown to be very well represented by the lognormal distribution, analysis procedures similar to those described previously for characterizing an individual site were applied. Table 6-12 lists the median EMCs for all sites within each land use category. The coefficient of variation quantifies the variability of site characteristics within the land use category. To the extent that the sites included in this database provide a "representative" sample of the land use classifications, then the information summarized by Table 6-12 indicates the effect of land use on urban storm runoff pollutant discharges.




(a) Tampa Sites

(b) WASHCOG Sites

Figure 6-15. Range of Normalized EMC Medians at FL1 and DC1

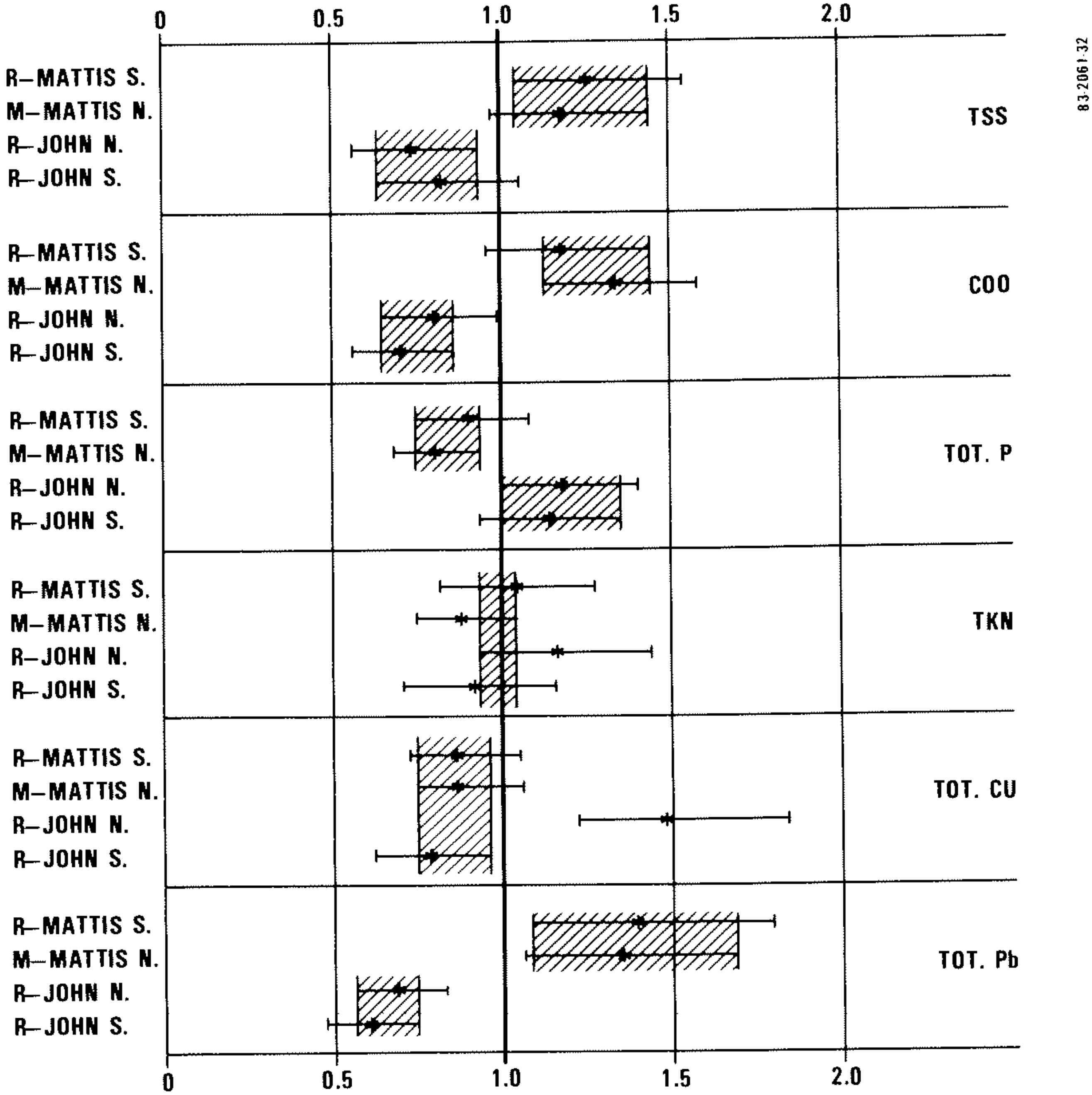



Figure 6-16. Range of Normalized EMC Medians at IL1

TABLE 6-12. MEDIAN EMCs FOR ALL SITES
BY LAND USE CATEGORY

| Pollutant | | Residential | | Mixed | | Commercial | | Open/Nonurban | |
|---|---|---|---|---|---|---|---|---|---|
| | | Median | CV | Median | CV | Median | CV | Median | CV |
| BOD | mg/ℓ | 10.0 | 0.41 | 7.8 | 0.52 | 9.3 | 0.31 | - | - |
| COD | mg/ℓ | 73 | 0.55 | 65 | 0.58 | 57 | 0.39 | 40 | 0.78 |
| TSS | mg/ℓ | 101 | 0.96 | 67 | 1.14 | 69 | 0.85 | 70 | 2.92 |
| Total Lead | μg/ℓ | 144 | 0.75 | 114 | 1.35 | 104 | 0.68 | 30 | 1.52 |
| Total Copper | μg/ℓ | 33 | 0.99 | 27 | 1.32 | 29 | 0.81 | - | - |
| Total Zinc | μg/ℓ | 135 | 0.84 | 154 | 0.78 | 226 | 1.07 | 195 | 0.66 |
| Total Kjeldahl Nitrogen | μg/ℓ | 1900 | 0.73 | 1288 | 0.50 | 1179 | 0.43 | 965 | 1.00 |
| $NO_2$ -N + $NO_3$ -N | μg/ℓ | 736 | 0.83 | 558 | 0.67 | 572 | 0.48 | 543 | 0.91 |
| Total P | μg/ℓ | 383 | 0.69 | 263 | 0.75 | 201 | 0.67 | 121 | 1.66 |
| Soluble P | μg/ℓ | 143 | 0.46 | 56 | 0.75 | 80 | 0.71 | 26 | 2.11 |

Some caution in the interpretation of the information presented in Table 6-12 is in order since statistical confidence limits are not given. These are indicated in Figure 6-17 (a through k), which illustrates land use differences graphically, with additional statistical detail derived from the basic parameters listed in Table 6-11, to assist in interpretation and comparisons. The box plots which compare characteristics of all sites within a land use category identify the land use, median EMC, its 90 percent confidence limits, and the 10, 25, 75 and 90 percent quantities for the sites. Careful perusal of these box plots leads one to the conclusion that only the open/non-urban land use category appears to be significantly different overall. Responses of the other land use categories are varied and inconsistent among constituents. This may be seen in a somewhat different way by observing the plotting positions of the land use categories presented in Figures 6-4 through 6-13. Here also, there are no consistent tendencies. There are undeniably some trends. For example, in Figure 6-7 commercial sites occupy the lowest plotting position at each project for total phosphorus (MI1 and one WI1 site are exceptions), which certainly suggests that there might be a land use category difference for this constituent.

Review of Figure 6-17(j), however, suggests that while a trend to lower total phosphorus EMC values is apparent as one goes from residential, to mixed, to commercial land uses, the statistical significance may not be great. The actual site median total phosphorus EMC probability density functions for each land use are presented in Figure 6-18. Here it can be seen that although three different pdfs can be drawn for residential, mixed, and commercial land use categories, their degree of overlap is so great that there is little statistical significance to the apparent difference. Since this was the strongest tendency towards land use effect, we must conclude that using this approach there is again no truly discernible and consistent effect of land use on the quality of urban runoff.

The one exception is the open/non-urban category which, as its name suggests, includes atypical sites. The data in Table 6-12 and the box plots of Figure 6-12 suggest that the pdfs for this land use category are quite different from those of the other land use categories, and this is in fact the case. Figure 6-18 shows it dramatically for total phosphorus.

Thus, regardless of the analytical approach taken, we are forced to conclude that, if land use category effects are present, they are eclipsed by the storm to storm variabilities and that, therefore, land use category is of little general use to aid in predicting urban runoff quality at unmonitored sites or in explaining site to site differences where monitoring data exist.

Correlation Between EMCs and Runoff Volume. To examine the possible relationship between the event mean concentration of a particular constituent and the runoff volume, linear correlation coefficients (r) were calculated. The null hypothesis that the two variables are linearly unrelated was tested at both the 90 and 95 percent confidence levels. Since it is possible for correlation to be either positive or negative, the two-tailed test was used. Failure to reject the null hypothesis is interpreted as meaning that linear dependency between the two variables in the population has not been shown.

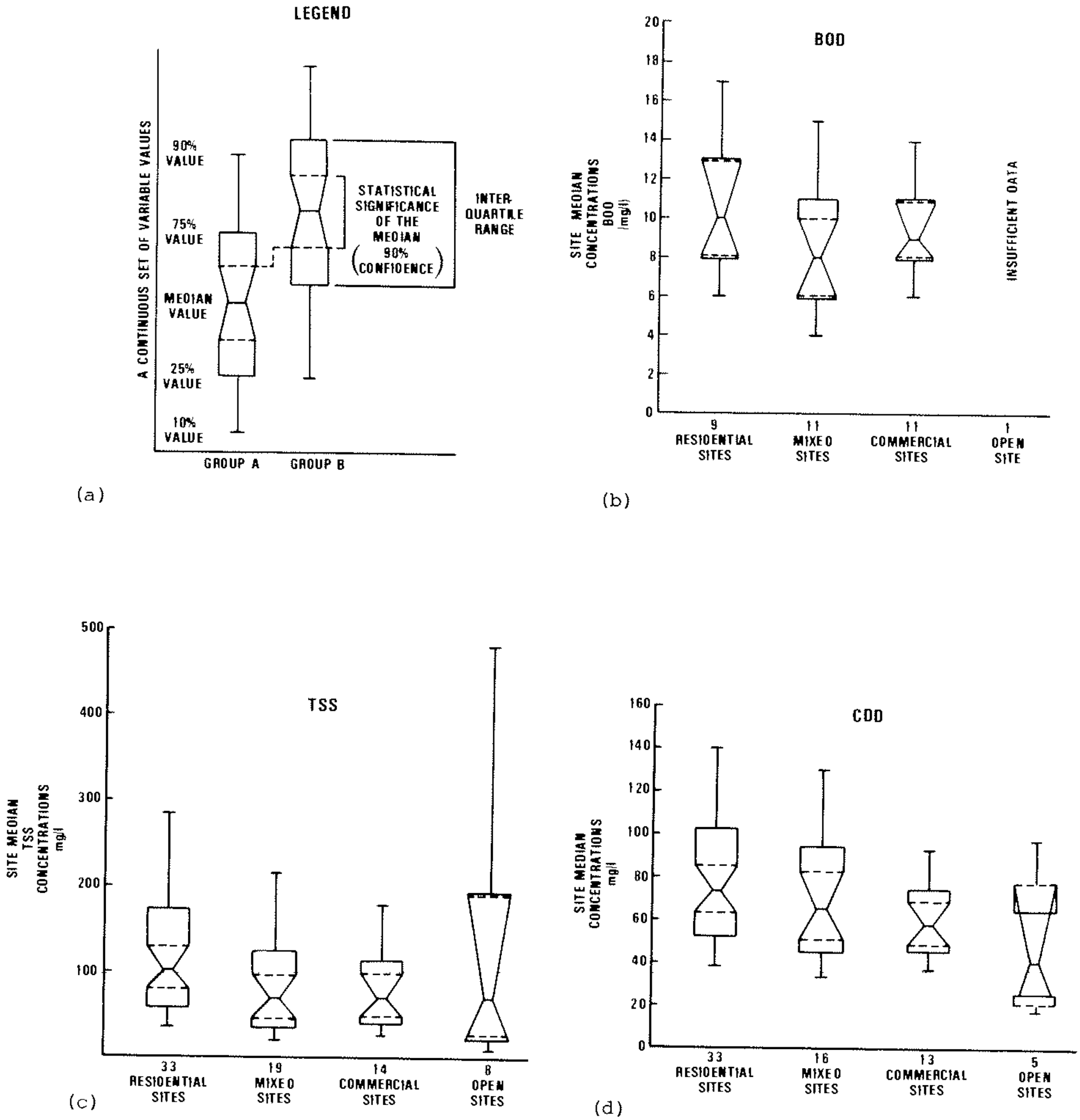



Figure 6-17. Box Plots of Pollutant EMCs for Different Land Uses

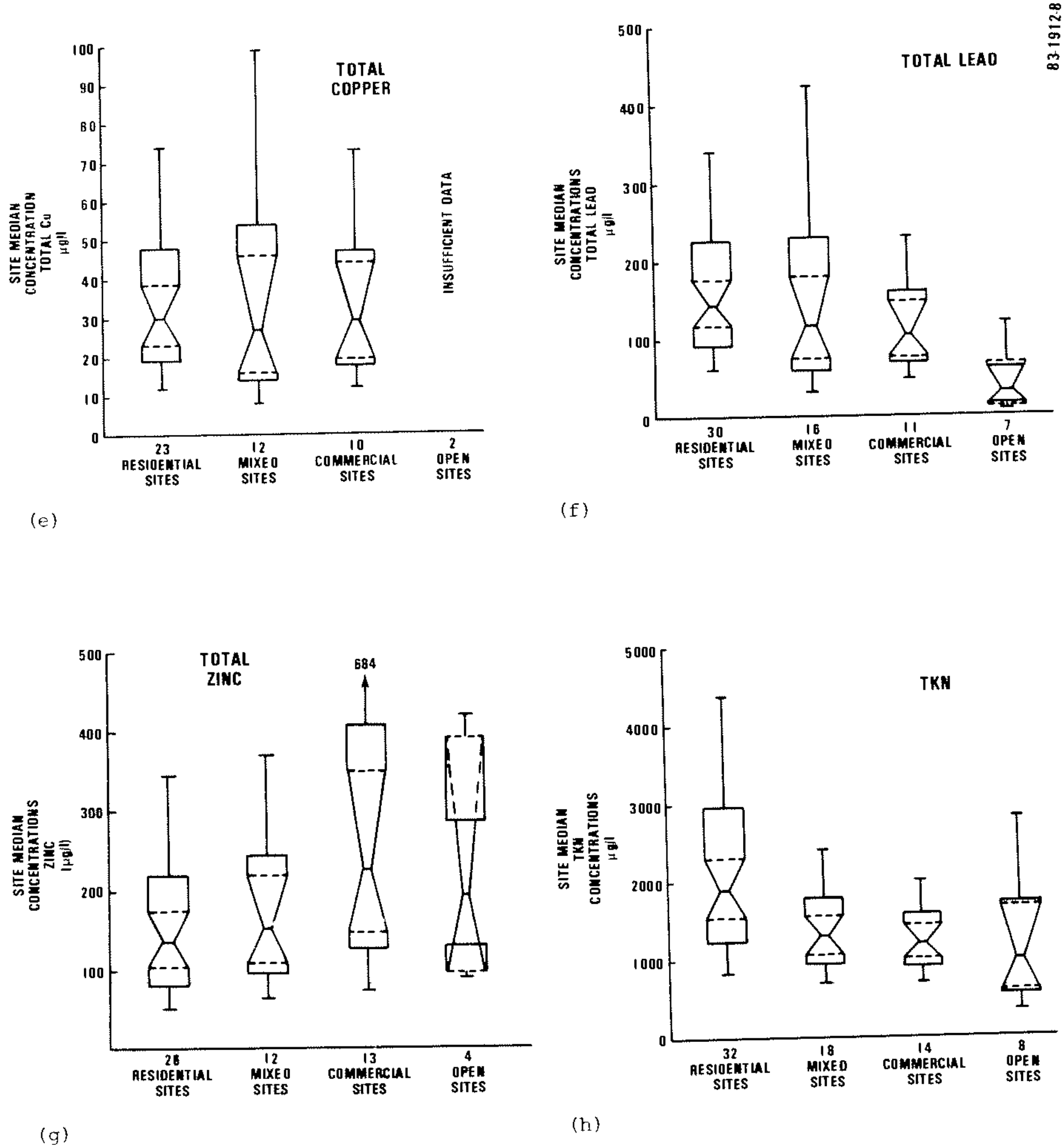
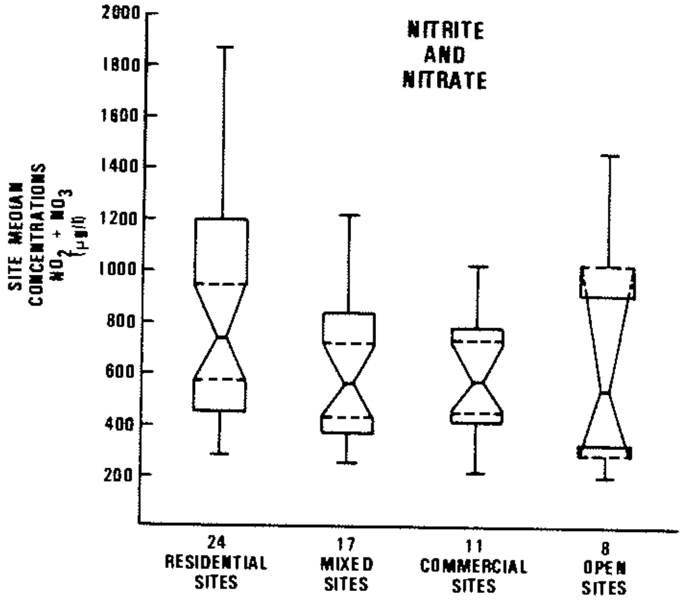
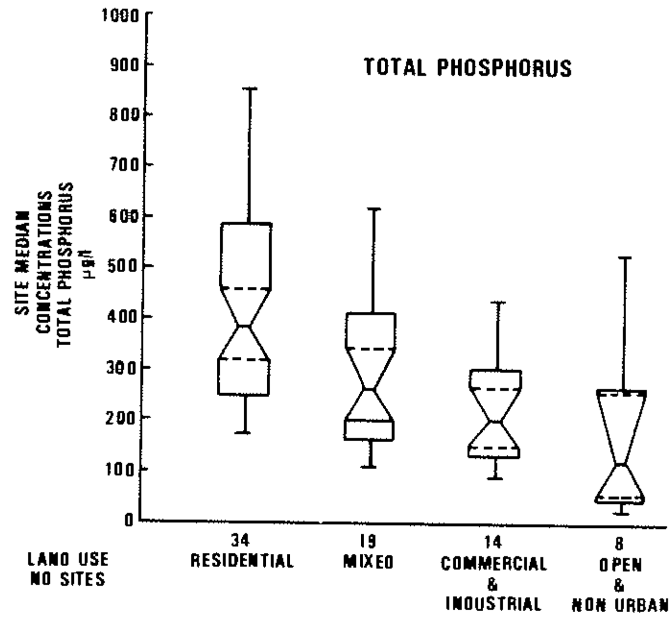


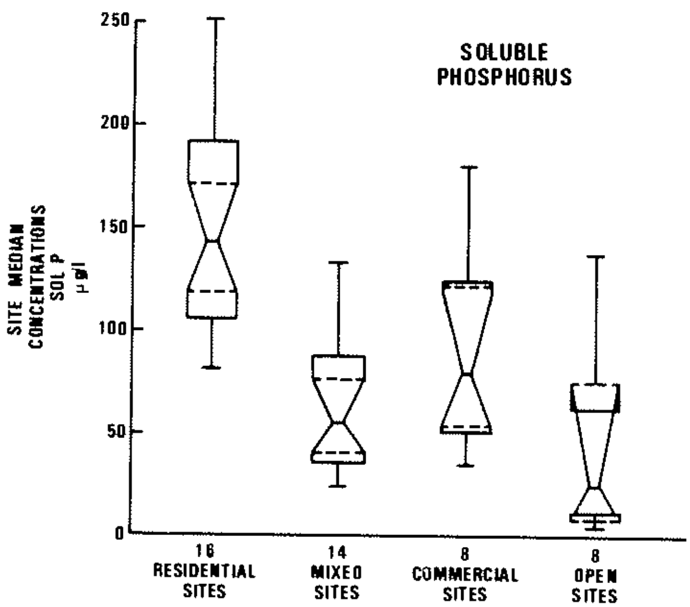

Figure 6-17. Box Plots of Pollutant EMCs for Different Land Uses (Cont'd)




(i)




(j)




83-1912.10

(k)

Figure 6-17. Box Plots of Pollutant EMCs for Different Land Uses (Cont'd)

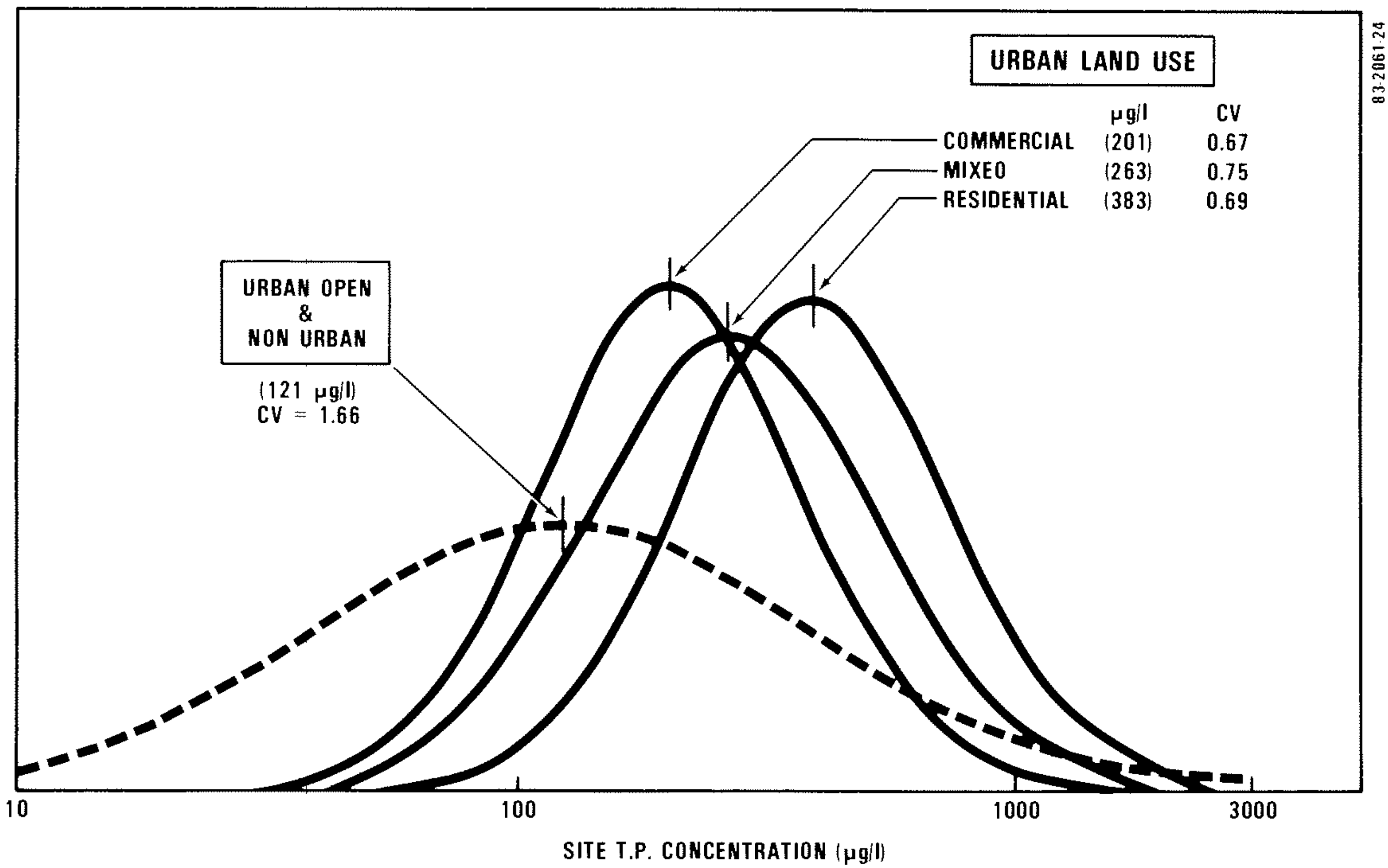



Figure 6-18. Site Median Total P EMC Probability Density Functions for Different Land Uses

The rejection of the null hypothesis means that there is evidence of a linear dependency between the two variables in the population, but it does not mean that a cause-and-effect relationship has been established.

General guidelines for the use of this test suggest that it be used with caution for values of n less than ten due to the high uncertainties associated with estimates of population variance with small samples. Furthermore, when n is 2 a perfect correlation will result but is meaningless. To include as many sites as possible in this examination, all constituents for which n was 5 or greater were included. At the other extreme, when n is very large, say over 100, correlation coefficients are almost always significant but can be so weak that they are meaningless. For n = 100 the critical value of r at the 90 percent confidence level is 0.164, meaning that the correlation explains less than 3 percent of the concentration variability.

A total of 67 sites from 20 of the NURP projects were examined for possible correlation for nine constituents. Of the 517 linear correlation coefficients calculated (not all constituents were measured at all sites), 116 (22 percent) were significant at the 95 percent confidence level and 154 (30 percent) were significant at the 90 percent confidence level. Of the r values that were significant, 83 and 87 percent were negative at the 90 and 95 percent confidence levels respectively. When sites with fewer than 10 events were dropped, the foregoing was essentially unchanged. Greater detail in terms of the number of significant linear correlation by constituent is provided in Table 6-13. There it can be seen that the greatest tendency for positive values of r occurs with TSS, followed by soluble phosphorus. The correlation coefficients for the other 7 constituents all strongly tend to be negative.

When the results are examined by sites, however, a clearer picture emerges. Although it can be correctly argued that unless a correlation coefficient is statistically significant the number is meaningless, it also follows that in such a case they are as likely to be positive as negative. On the other hand, if all the correlation coefficients (whether significant or not) have the same sign, it suggests a tendency for that site. The sign of the correlation coefficient (if greater than 0.1) for each site and constituent examined is given in Table 6-14. Giving appropriate weight to significant r values but considering others as well, some 37 of the sites tend to have negative correlations, 13 tend to be positive, and the remaining 17 tend to be mixed. Perusal of Table 6-14 reveals that this tendency for sites to have either positive or negative correlation coefficients is quite strong, especially for sites with a large number of significant correlations. Sites where erosion, scour, system lag, and such are present could be expected to exhibit a tendency towards positive correlations. Sites lacking such effects could be expected to have negative correlation due to dilution associated with larger runoff events.

The magnitude of the correlation coefficients is indicated in Table 6-15. Two points stand out in particular. First, the r values are not very large, averaging around 0.55. This means that the correlation is only able to explain about 30 percent of the concentration variability. The few high values are always associated with very few observations ($n<10$) for which the

TABLE 6-13. NUMBER OF SIGNIFICANT LINEAR CORRELATIONS BY CONSTITUENT

83 2061 37

| POLLUTANT | TOTAL # OF SITES | 90% SIGNIFICANT CORRELATION | | | 95% SIGNIFICANT CORRELATION | | |
|---|---|---|---|---|---|---|---|
| | | TOTAL # | # NEG. | # POS. | TOTAL # | # NEG. | # POS. |
| **(a) ALL SITES** | | | | | | | |
| TSS | 67 | 13 (19%) | 4 | 9 | 7 (10%) | 3 | 4 |
| COD | 64 | 24 (38%) | 23 | 1 | 19 (30%) | 19 | 0 |
| TOT. P | 67 | 20 (30%) | 16 | 4 | 15 (22%) | 12 | 3 |
| SOL. P | 34 | 10 (29%) | 6 | 4 | 7 (21%) | 4 | 3 |
| TKN | 64 | 19 (30%) | 18 | 1 | 14 (22%) | 14 | 0 |
| $NO_{2+3}$-N | 57 | 17 (30%) | 15 | 2 | 13 (23%) | 11 | 2 |
| TOT. Cu | 49 | 17 (35%) | 15 | 2 | 13 (27%) | 12 | 1 |
| TOT. Pb | 59 | 15 (25%) | 13 | 2 | 12 (20%) | 11 | 1 |
| TOT. Zn | 56 | 19 (34%) | 18 | 1 | 16 (29%) | 15 | 1 |
| TOTAL | 517 | 154 | 128 | 26 | 116 | 101 | 15 |
| PERCENT | | 30% | 83% | 17% | 22% | 87% | 13% |
| **(b) SITES WITH n $\geq$ 10** | | | | | | | |
| TSS | 56 | 9 (16%) | 4 | 5 | 7 (12%) | 3 | 4 |
| COD | 52 | 21 (40%) | 20 | 1 | 16 (31%) | 16 | 0 |
| TOT. P | 53 | 17 (32%) | 15 | 2 | 12 (23%) | 11 | 1 |
| SOL. P | 23 | 8 (35%) | 5 | 3 | 6 (26%) | 4 | 2 |
| TKN | 50 | 17 (34%) | 16 | 1 | 12 (24%) | 12 | 0 |
| $NO_{2+3}$-N | 41 | 14 (34%) | 12 | 2 | 12 (29%) | 10 | 2 |
| TOT. Cu | 31 | 13 (42%) | 12 | 1 | 12 (39%) | 11 | 1 |
| TOT. Pb | 45 | 13 (29%) | 12 | 1 | 11 (24%) | 10 | 1 |
| TOT. Zn | 37 | 14 (38%) | 13 | 1 | 11 (30%) | 10 | 1 |
| TOTAL | 388 | 126 | 109 | 17 | 99 | 87 | 12 |
| PERCENT | | 32% | 87% | 13% | 26% | 88% | 12% |

TABLE 6-14. SIGN OF CORRELATION COEFFICIENTS BY SITES

83-2061-33

| Site | Station | TSS | COD | TOT. P | SOL. P | TKN | $NO_{2+3}$-N | TOT. CU | TOT. Pb | TOT. ZN |
|---|---|---|---|---|---|---|---|---|---|---|
| CA1 | KNOX | + | − | + | ⊕ | | ⊕ | − | − | |
| | S. VIEW. | ⊕ | + | | | ⊕ | | + | − | + |
| CO1 | ASBURY | ⊕ | + | ⊕ | + | + | − | ⊕ | + | + |
| | B. DRY C. | | − | − | − | ⊖ | − | − | | − |
| | CHERRY | | | + | ⊕ | | − | + | | |
| | N. AVE. | | ⊖ | ⊖ | ⊖ | ⊖ | ⊖ | ⊖ | ⊖ | ⊖ |
| | ROONEY | − | ⊖ | − | − | − | − | − | − | ⊖ |
| | VILLA IT. | − | ⊖ | ⊖ | ⊖ | ⊖ | ⊖ | ⊖ | ⊖ | ⊖ |
| | 116/C | + | − | ⊕ | | | − | + | | + |
| DC1 | DUFIEF | − | ⊖ | + | − | − | − | | | − |
| | FAIRIDGE | | + | + | + | + | | | | + |
| | LAKERIDGE | + | | + | ⊕ | | ⊖ | | − | ⊖ |
| | STEDWICK | | − | | + | | ⊖ | + | − | ⊖ |
| | STRATTON | + | − | | | + | | − | | − |
| | WESTLEIGH | | ⊖ | | | − | ⊖ | ⊖ | − | ⊖ |
| FL1 | CHARTER/H | − | ⊖ | ⊖ | | ⊖ | − | ⊖ | ⊖ | ⊖ |
| | YOUNG | | − | − | | | − | + | | |
| | NORMA P. | + | + | | | | + | | | − |
| IL1 | JOHN N. | + | ⊖ | ⊖ | | ⊖ | | − | − | |
| | JOHN S. | + | ⊖ | ⊖ | | − | | − | | |
| | MATTIS N. | | ⊖ | ⊖ | | ⊖ | | ⊖ | ⊖ | |
| | MATTIS S. | − | ⊖ | ⊖ | | ⊖ | | ⊖ | ⊖ | |
| KS1 | 92nd | − | + | − | + | + | | | | |

| Site | Station | TSS | COD | TOT. P. | SOL P | TKN | NO 2+3-N | TOT. CU | TOT. Pb | TOT. ZN |
|---|---|---|---|---|---|---|---|---|---|---|
| KS1 | LENAXA | + | ⊖ | ⊖ | − | − | | ⊖ | | |
| | METCALF | | − | − | − | − | | − | | − |
| | NOLAND | | ⊖ | − | ⊖ | | | + | − | − |
| | OVERTON | + | | + | | | | − | − | ⊖ |
| MA1 | ANNA | + | | + | | + | − | | − | + |
| | CONVENT | − | + | | + | − | − | + | | + |
| | JORDAN | | | + | + | − | ⊖ | − | | ⊖ |
| | LOCUST | ⊕ | + | ⊕ | + | + | ⊖ | + | ⊕ | |
| | RT. 9 | + | | | + | − | ⊖ | + | + | |
| MA2 | ADDISON | ⊕ | | − | − | + | − | | | |
| | HEMLOCK | ⊕ | | + | ⊕ | + | − | | | |
| MO1 | BOLTON | ⊕ | − | + | | − | − | ⊖ | + | − |
| | HAMPDEN | | − | ⊖ | | | | ⊖ | | − |
| | HOMELAND | + | + | + | | − | + | − | + | + |
| | MT. WASH. | ⊕ | − | − | | − | − | + | − | − |
| | RES. HILL | + | ⊖ | | | ⊖ | | ⊖ | − | − |
| MI1 | GRACE S. | + | − | − | | − | − | ⊖ | − | − |
| | GRACE N. | + | − | | + | | | | | ⊖ |
| | GRAND | | − | − | | − | | − | − | ⊖ |
| | IND. DR. | + | | + | + | | − | − | − | − |
| | WAVERLY | | − | − | − | − | − | − | | − |
| NC1 | 1013 | | ⊖ | ⊖ | | ⊖ | ⊖ | ⊖ | ⊖ | ⊖ |
| | 1023 | ⊕ | | + | | | − | + | | |
| NH1 | PKG. | − | ⊖ | − | | ⊖ | ⊖ | ⊖ | ⊖ | ⊖ |

| Site | Station | TSS | COD | TOT. P | SOL. P | TKN | $NO_{2+3}$-N | TOT. CU | TOT. Pb | TOT. ZN |
|---|---|---|---|---|---|---|---|---|---|---|
| NY1 | CARLL R. | + | | | | | ⊖ | | | |
| NY2 | CEDAR | | | | + | | ⊕ | | + | |
| NY3 | CRANSTON | + | + | + | | − | | | − | − |
| | E. ROCH. | − | ⊖ | ⊖ | | ⊖ | | | ⊖ | ⊖ |
| | SOUTHGATE | + | − | + | − | | | | | − |
| TN1 | CBD | ⊖ | − | ⊖ | ⊖ | ⊖ | − | ⊖ | ⊖ | ⊖ |
| | R1 | ⊕ | + | + | ⊖ | + | − | ⊕ | ⊕ | ⊕ |
| | R2 | + | − | − | − | ⊖ | − | | | − |
| | SC | + | | − | ⊖ | − | ⊖ | | + | |
| TX1 | HART | + | ⊕ | | | + | + | | | |
| | R'WOOD. | − | + | | | ⊖ | | | | |
| WA1 | LAKE H. | − | ⊖ | − | | ⊖ | | + | ⊖ | ⊖ |
| | SURREY D. | − | ⊖ | ⊖ | | ⊖ | | | ⊖ | ⊖ |
| WI1 | BURBANK | | − | ⊕ | | | | | | + |
| | HASTINGS | | ⊖ | − | | + | + | | ⊖ | − |
| | LINCOLN | | − | − | | | − | | + | |
| | POST D. | ⊖ | ⊖ | ⊖ | | ⊖ | ⊖ | | ⊖ | − |
| | RUSTLER | ⊖ | ⊖ | − | | ⊖ | ⊖ | | | − |
| | STATE F. | ⊖ | ⊖ | ⊖ | | − | ⊖ | | − | + |
| | WOOD C. | | | | | − | − | | | + |

\+ INDICATES A POSITIVE R VALUE

− INDICATES A NEGATIVE R VALUE

◯ INDICATES A SIGNIFICANT R VALUE

BLANK INDICATES EITHER R LESS THAN 0.1 OR NO DATA

TABLE 6-15. CORRELATION COEFFICIENT VALUES BY SITE

| Site | | TSS | COD | TOT. P | SOL. P | TKN | $NO_{2+3}$-N | TOT. CU | TOT. Pb | TOT. ZN |
|---|---|---|---|---|---|---|---|---|---|---|
| CA1 | KNOX | | | | .43 | | .70 | | | |
| | S. VIEW. | .57 | | | | .49 | | | | |
| CO1 | ASBURY | .58 | | .84 | | | | .58 | | |
| | B. DRY C. | | | | | -.47 | | | | |
| | CHERRY | | | | .10 | | | | | |
| | N. AVE. | | -.58 | -.47 | -.42 | -.72 | -.52 | -.47 | -.42 | -.41 |
| | ROONEY | | -.78 | | | | | | | -.75 |
| | VILLA IT. | | .70 | -.58 | -.67 | -.69 | -.44 | -.46 | -.55 | -.61 |
| | 116/C | | | .85 | | | | | | |
| DC1 | DUFIEF | | .76 | | | | | | | |
| | FAIRIDGE | | | | | | | | | |
| | LAKERIDGE | | | | .42 | | -.28 | | | -.41 |
| | STEDWICK | | | | | -.2 | -.28 | | | -.26 |
| | STRATTON | | | | | | | | | |
| | WESTLEIGH | | .32 | | | | -.38 | -.94 | | -.44 |
| FL1 | CHARTER/H | | -.82 | .54 | U | .68 | | -.54 | -.67 | -.58 |
| | YOUNG | | | | U | | | | | |
| | NORMA P. | | | | U | | | | | |
| IL1 | JOHN N. | | -.31 | .39 | U | -.29 | U | | | U |
| | JOHN S. | | .36 | -.42 | U | | U | | | U |
| | MATTIS N. | | -.84 | .58 | U | -.48 | U | -.40 | .46 | U |
| | MATTIS S. | | -.81 | -.56 | U | .53 | U | .34 | -.46 | U |
| KS1 | 92nd | | | | U | | U | | | |

| Site | | TSS | COD | TOT P. | SOL P | TKN | NO 2+3-N | TOT. CU | TOT. Pb | TOT. ZN |
|---|---|---|---|---|---|---|---|---|---|---|
| KS1 | LENAXA | | -.70 | .51 | U | | U | -.80 | | |
| | METCALF | | .40 | -.40 | U | | U | | | |
| | NOLAND | | -.77 | | -.82 | U | U | | | |
| | OVERTON | | | | | U | U | | | -.57 |
| MA1 | ANNA | | | | | | | | | |
| | CONVENT | | | | | | | | | |
| | JORDAN | | | | | | .68 | | | .74 |
| | LOCUST | .80 | | .91 | | | -.82 | | .78 | |
| | RT. 9 | | | | | | -.87 | | | |
| MA2 | ADDISON | .83 | U | | | | | | | |
| | HEMLOCK | .85 | U | | .94 | | | | | |
| MO1 | BOLTON | .50 | | | U | | | .47 | | |
| | HAMPDEN | | | .42 | U | | | -.61 | | |
| | HOMELAND | | | | U | | | | | |
| | MT. WASH. | .42 | | | U | | | | | |
| | RES. HILL | | -.79 | | U | -.58 | | -.55 | | |
| MI1 | GRACE S. | | | | | | | .70 | | |
| | GRACE N. | | | | | | | | | .80 |
| | GRAND | | | | | | | | | -.51 |
| | IND. DR. | | | | | | | | | |
| | WAVERLY | | | | | | | | | |
| NC1 | 1013 | | -.58 | .49 | U | -.57 | -.67 | -.32 | .29 | .64 |
| | 1023 | .32 | | | U | | | | | |
| NH1 | PKG. | | -.58 | | U | .48 | -.46 | -.50 | .41 | -.58 |

| Site | | TSS | COD | TOT. P | SOL. P | TKN | $NO_{2+3}$-N | TOT. CU | TOT. Pb | TOT. ZN |
|---|---|---|---|---|---|---|---|---|---|---|
| NY1 | CARLL R. | | U | | U | | -.70 | U | | |
| NY2 | CEDAR | | U | | | | .42 | U | | |
| NY3 | CRANSTON | | | | U | | U | U | | |
| | E. ROCH. | | .79 | -.84 | U | .70 | U | U | -.72 | -.72 |
| | SOUTHGATE | | | | U | | U | U | | |
| TN1 | CBO | .48 | | -.82 | -.47 | .56 | | .51 | -.51 | .85 |
| | R1 | .82 | | | -.62 | | | .72 | .85 | .82 |
| | R2 | | | | | .81 | | | | |
| | SC | | | | -.49 | | .85 | | | |
| TX1 | HART | | .57 | | U | | | U | | |
| | R'WOOD. | | | | U | -.77 | | U | | |
| WA1 | LAKE H. | | .33 | | U | -.34 | | | -.29 | .37 |
| | SURREY D. | | -.38 | -.30 | U | -.21 | | U | -.18 | -.23 |
| WI1 | BURBANK | | | .26 | U | | | U | | |
| | HASTINGS | | .49 | | U | | | U | -.32 | |
| | LINCOLN | | | | U | U | | U | | U |
| | POST O. | -.39 | -.28 | .24 | U | -.48 | -.53 | U | .23 | |
| | RUSTLER | -.37 | .55 | | U | .39 | .37 | U | | |
| | STATE F. | .47 | .48 | .47 | U | | .72 | U | | |
| | WOOD C. | | | | U | | | U | | |

83-2061-34

INDICATES 95% LEVEL OF SIGNIFICANCE, OTHERS ARE AT THE 90% LEVEL
U INDICATES AN UNMEASURED CONSTITUENT
BLANK INDICATES NO SIGNIFICANT CORRELATION

test is suspect since one or two events may dominate the correlation or otherwise cause it to be overstated due to uncertainties in parameter estimation. Second, only 25 percent of the sites account for over two-thirds of the significant correlations. In fact, 33 of the 67 sites had at most one significant correlation, 16 had 2 or 3, and 18 had 4 or more significant r values.

Data for the sites with many significant correlations are presented in Table 6-16. It can be noted that the r values for all constituents are around 0.55. Thus, there is no overall tendency to have strong correlations for some constituents and weak correlations for others. On a site by site basis, the strength of the apparent correlation varies inversely with n as does the significance requirement. Discounting the sites with very low or high values of n, however, the r values for the remainder are again around 0.55, which is the average for all 19 of these sites. Turning to land use, it is significant that half of the sites with many significant correlations have a large commercial/industrial component. Discounting sites with a small number of observations ($n \leq 12$), the sites in Table 6-16 are smaller (average size is 41 acres vs 126 acres for all sites), more impervious (average of 65 percent vs 40 percent for all sites), and have higher runoff coefficients (0.5 vs 0.3 for all sites). Thus, one could conjecture that their responses might tend to be somewhat less random and more ameanable to deterministic analysis (i.e., with conventional modeling approaches). Since they represent only around 25 percent of the total number of sites, however, and the correlations are rather weak, any effect of EMC correlation with runoff volume can be ignored without serious overall error.

This finding of no significant linear correlation between EMCs and runoff volumes is important for several reasons. First, in stormwater monitoring programs there is a natural and appropriate bias that favors emphasizing resource allocation to larger storm events. This was generally the case with the NURP projects as well. However, because of differences in local meteorological conditions, degree of site imperviousness, and other factors, there are appreciable differences in the average sizes of storms monitored by site in the NURP database. Since no significant linear correlation was found, such biases and differences are not expected to influence EMC comparisons to any appreciable extent.

Secondly, the probabilistic methodologies for examining receiving water impacts identified in Chapter 5 assume, as they are now structured, that concentration and runoff volume are independent (i.e., that there is no significant correlation). Although the methods can be modified to account for such correlations if they exist, the finding of no significant correlation indicates that such refinement is not warranted at this time.

Other Factors. We have not exhaustively analyzed all potential effects of other factors that might influence and hence modify our interpretations and conclusions regarding site differences. Factors such as slope, population density, soil type, seasonal bias in monitored events, and precipitation characteristics (average rainfall intensity, peak rainfall intensity, rainfall duration, time since last storm event, etc.) all have a potential

TABLE 6-16. SITES WITH MANY SIGNIFICANT CORRELATIONS

| | | TSS | COD | TOT. P | SOL. P | TKN | $NO_{2+3}$-N | Cu | Pb | Zn | AVG $r^2$ | AVG r | $\bar{n}$ | LAND USE | % IMPERVIOUS | RUNOFF COEFFICIENT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CO1 | NORTH AVE. | – | –.58 | –.47 | –.42 | –.72 | –.52 | –.47 | –.42 | –.46 | .28 | 52 | 32 | 30%C | 50% | .239 |
| | VILLA IT. | – | –.70 | –.5B | –.67 | –.69 | –.44 | –.46 | –.55 | –.65 | .35 | .59 | 27 | 100%C | 91% | .927 |
| OC1 | WESTLEIGH | – | –.32 | – | – | – | –.39 | –.84 | – | –.44 | .29 | .54 | 35 | 93%R | 21% | .119 |
| FL1 | CHARTER/H | – | –.62 | –.54 | U | –.68 | – | –.54 | –.67 | –.56 | .37 | .60 | 12 | 89%R | 16% | .153 |
| IL1 | MATTIS N. | – | –.64 | –.59 | U | –.48 | U | –.40 | –.46 | U | .27 | .52 | 35 | 50%C | 58% | .639 |
| | MATTIS S. | – | –.61 | –.55 | U | –.53 | U | –.34 | –.46 | U | .26 | .51 | 33 | 90%R | 37% | .330 |
| KS1 | LENAXA | – | –.70 | –.51 | U | – | U | –.80 | – | – | .46 | .68 | 16 | 50%I | 44% | .540 |
| MA 1 | LOCUST | .80 | – | .91 | – | – | –.82 | – | .78 | – | .69 | .83 | 6 | 85%R | 16% | .209 |
| MO-1 | RES. HILL | – | –.79 | – | U | –.58 | – | –.55 | – | – | .42 | .65 | 13 | 100%R | 76% | .4B6 |
| NC1 | 1013 (CBO) | – | –.58 | –.46 | U | –.57 | –.67 | –.32 | –.29 | –.54 | .26 | .51 | 61 | 100%C | 69% | .791 |
| NH1 | PKG. | – | –.5B | – | U | –.49 | –.46 | –.50 | –.41 | –.58 | .26 | .51 | 33 | 100%C | 90% | .658 |
| NY3 | E. ROCHESTER | – | –.79 | –.84 | U | –.70 | U | U | –.72 | –.72 | .57 | .76 | 8 | 100%R | 38% | .195 |
| TN1 | CBO | –.48 | – | –.62 | –.47 | –.56 | – | –.51 | –.51 | –.65 | .30 | .55 | 15 | 100%C | 99% | .206 |
| | R1 | .82 | – | – | –.62 | – | – | .72 | .85 | .82 | .57 | .77 | 11 | 91%R | 33% | .032 |
| WA-1 | LAKE H. | – | –.33 | – | U | –.34 | U | U | –.29 | –.37 | .11 | .33 | 126 | 91%R | 37% | .199 |
| | SURREY O. | – | –.34 | –.30 | U | –.21 | U | U | –.18 | –.23 | .07 | .26 | 118 | 100%R | 29% | .177 |
| WI1 | P.O. | –.39 | –.28 | –.24 | U | –.46 | –.53 | U | –.23 | – | .14 | .37 | 40 | 100%C | 95% | .899 |
| | RUSTLER | –.37 | –.55 | – | U | –.39 | –.37 | U | – | – | .18 | .43 | 20 | 100%C | 95% | .793 |
| | STATE FAIR | –.47 | –.48 | –.47 | U | – | –.72 | U | – | – | .30 | .55 | 25 | 74%C | 77% | .622 |
| | AVERAGE $r^2$ | .34 | .33 | .29 | .31 | .30 | .30 | .31 | .28 | .32 | | | | | | |
| | AVERAGE r | .58 | .58 | .53 | .55 | .55 | .55 | .56 | .53 | .57 | | | | | | |

influence on the median and variability of pollutant concentrations at a site.

On the basis of limited screening, however, we have concluded that such factors do not appear to have any real consistent significance in explaining observed similarities or differences among individual sites. Therefore, although more detailed and rigorous analysis and evaluation of the NURP database may well provide additional useful insight and understanding of the influence of such other factors, we do not believe that the basic findings and conclusions presented in this report will be significantly altered by the results of such efforts. Furthermore, the value of any such insights as may be developed are likely to have limited influence on general decisions on control of urban runoff. For example, the finding of a strong seasonal effect on EMC values would have little influence on a decision to require detention basins in all newly developing urban areas, nor would it be likely to influence their design.

Urban Runoff Characteristics

Having determined, as discussed in the preceding section, that geographic location, land use category, or other factors appear to be of little utility in explaining overall site-to-site variability or predicting the characteristics of unmonitored sites, the best general characterization of urban runoff can be obtained by pooling the site data for all sites (other than the open/non-urban ones). This approach is appropriate, given the need for a nationwide assessment and the general planning thrust of this report. Recognizing that there tend to be exceptions to any generalization, however realistic and appropriate, in the absence of better information the data given in Table 6-17 are recommended for planning level purposes as the best description of the characteristics of urban runoff.

TABLE 6-17. WATER QUALITY CHARACTERISTICS OF URBAN RUNOFF

| Constituent | Event to Event Variability in EMC's (Coef Var) | Site Median EMC | |
|---|---|---|---|
| | | For Median Urban Site | For 90th Percentile Urban Site |
| TSS (mg/l) | 1-2 | 100 | 300 |
| BOD (mg/l) | 0.5-1.0 | 9 | 15 |
| COD (mg/l) | 0.5-1.0 | 65 | 140 |
| Tot. P (mg/l) | 0.5-1.0 | 0.33 | 0.70 |
| Sol. P (mg/l) | 0.5-1.0 | 0.12 | 0.21 |
| TKN (mg/l) | 0.5-1.0 | 1.50 | 3.30 |
| $NO_{2+3}$-N (mg/l) | 0.5-1.0 | 0.68 | 1.75 |
| Tot. Cu (μg/l) | 0.5-1.0 | 34 | 93 |
| Tot. Pb (μg/l) | 0.5-1.0 | 144 | 350 |
| Tot. Zn (μg/l) | 0.5-1.0 | 160 | 500 |

Coliform Bacteria

Coliform bacteria counts in urban runoff were monitored for a significant number of storm events by seven of the NURP projects at 17 different sites. Data were collected at twelve of these sites for more than five and up to 20 storm events. Data on either Fecal Coliform or both Fecal and Total Coliform counts are available for a total of 156 separate storm events. Although the data base for bacteria is thus considerably more restricted than for other pollutants, useful results have been obtained.

Table 6-18 summarizes the results of an analysis of these data. Some variability exists from site to site, and data are too limited to identify any land use distinctions. However, results from the different sites and projects are consistent in showing a very dramatic seasonal effect. Coliform counts in urban runoff during the warmer periods of the year are approximately 20 times greater than those in urban runoff that occurs during colder periods.

The substantial seasonal differences which are observed do not correspond with comparable variations in urban activities. This suggests that seasonal temperature effects and sources of coliform unrelated to those traditionally associated with human health risk may be significant.

In addition to the summarized data presented here, special study reports prepared by the Long Island and Baltimore projects address the issue of animal and other sources of coliform bacteria using information derived from field monitoring and the technical literature. The Baltimore NURP project also conducted small scale site studies which simulated washoff by storms and identified that quite substantial differences in coliform levels can result from the general cleanliness of an area, which they associate with the socio-economic strata of the neighborhood. A special study by the Long Island NURP project examined salmonella counts in urban runoff and in an adjacent shellfish area influenced by urban runoff. The Knoxville, TN project also conducted a special study on Salmonella. These project reports may be obtained through NTIS.

Other issues related to bacteria as a health risk were raised and warrant further investigation. A better understanding is needed of the contribution of domestic animals or such wildlife as may be expected in urban areas to observed coliform levels.

Though high levels of indicator microorganisms were found in urban runoff, the analysis as well as current literature suggests that indicators such as fecal coliform may not be useful in identifying health risks from urban runoff pollutions.

PRIORITY POLLUTANTS

'ackground

he NURP priority pollutant monitoring project was conducted to evaluate the resence, concentration, and potential water quality impacts of priority polutants in urban runoff. A total of 121 urban runoff samples were collected

TABLE 6-18. FECAL COLIFORM CONCENTRATIONS IN URBAN RUNOFF

| Project and Site | | Warm Weather | | | Cold Weather | | |
|---|---|---|---|---|---|---|---|
| | | Site No. Obs | Median EMC (1000/ 100 ml) | C.V. | Site No. Obs | Median EMC (1000/ 100 ml) | C.V. |
| DC1 | Burke | 1 | 4.6 | - | 1 | 0.02 | - |
| | Westleigh | 1 | 46 | - | 2 | 0.35 | - |
| | Stedwick | 2 | 10 | - | 1 | 0.2 | - |
| MD1 | Homeland | 7 | 11 | 1.8 | - | - | - |
| | Mt Wash | 1 | 130 | - | 1 | 3.3 | - |
| | Res Hill | 1 | 281 | - | 1 | 330 | - |
| NC1 | (CBD) 1013 | 11 | 15 | 1.6 | 8 | 1.0 | 0.6 |
| | Res 1023 | 2 | 23 | - | 4 | 2.6 | 1.1 |
| NH1 | Pkg Lot | 20 | 0.3 | 0.5 | - | - | - |
| NY1 | Carll | 12 | 24 | 0.9 | 15 | 1.4 | 1.5 |
| | Unqua | 7 | 11 | 1.6 | 4 | 0.9 | 14 |
| SD1 | Meade | 9 | 57 | 0.7 | - | - | - |
| TN1 | CBD | 7 | 54 | 1.5 | 7 | 1.0 | 1.4 |
| | R1 | 6 | 56 | 2.0 | 4 | 1.6 | 1.9 |
| | R2 | 6 | 19 | 6.2 | 4 | 0.5 | 2.4 |
| | SC | 7 | 12 | 2.8 | 4 | 0.9 | 1.7 |
| | | 76 Events | | | 52 Events | | |
| All Sites* | | 11 | 21 | 0.8 | 9 | 1 | 0.7 |

Notes:

* For general characterization of urban runoff, exclude the following sites:

- NH1 - A small (0.9A) Parking Lot; concentrations low and atypical.
- Four sites with only one observation for season; variability is too high for any confidence in representativeness of a single value.

at 61 sites (two storm events per site) in 20 of the NURP projects that participated in this phase of the program. These sites were predominantly in the residential, mixed, or commercial land use areas as defined earlier. Thus, the results of this effort cannot be attributed to runoff from industrial facilities or complexes. Furthermore, an especially exhaustive quality control component, over and above the standard NURP QA/QC effort, was imposed on the priority pollutant portion of the program, resulting in the rejection of nearly 14 percent of the data. Therefore, there is a high level of confidence in the results of this project.

Since only two samples were collected at each site, no meaningful site statistic could be calculated. Therefore the data were pooled for analysis. In view of the discussion in the preceding section, however, this approach seems to be justified.

A detailed compilation of NURP priority pollutant analytical results including city and site where the sample was collected, date of collection; discrete or composite sample, pH, and pollutant concentration can be found in the final report on the NURP Priority Pollutant Monitoring Program soon to be issued by the Monitoring and Data Support Division of the agency. A summary of the findings taken from the December 5, 1983 draft of that report follows.

Pollutants Not Included in NURP. Asbestos and dioxin were excluded from the NURP program. However, standard laboratory methods will reveal the presence of dioxin at concentrations of 1 to 10 μg/l, and most laboratories did scan their chromatograms for the possible presence of this pollutant. All such scans were negative, and on this basis dioxin is included as "not detected".

Results Not Valid. The NURP results for seven priority pollutants cannot be considered valid. Recent EPA investigation has revealed that standard methods are not appropriate for the measurement of hexachlorocyclopentadiene, dimethyl nitrosamine, diphenyl nitrosamine, benzidine, and 1,2-diphenylhydrazine. Two other pollutants, acrolein and acrylonitrile, must be analyzed within three days of sample collection. Such a time constraint was an impractical one for the NURP program.

Pollutants Detected in Runoff

Seventy-seven priority pollutants were detected in the NURP urban runoff samples. This group includes 14 inorganic and 63 organic pollutants (Table 6-19).

Inorganic Pollutants. As a group, the toxic metals are by far the most prevalent priority pollutant constituents of urban runoff. All 14 inorganics (13 metals, plus cyanides; asbestos excluded) were detected, and all but three at frequencies of detection greater than 10 percent. Most often detected among the metals were copper, lead, and zinc, all of which were found in at least 91 percent of the samples. Their concentrations were also among the highest for any pollutant, and reached a maximum of 100, 460, and 2,400 μg/l, respectively. Other frequently detected inorganics included arsenic, chromium, cadmium, nickel, and cyanide (Table 6-20). Twelve of the thirteen toxic metals (antimony excluded) were also sampled in the special

TABLE 6-19. SUMMARY OF ANALYTICAL CHEMISTRY FINDINGS FROM NURP PRIORITY POLLUTANT SAMPLES[1]

(Includes information received through September 30, 1983)

| Pollutant | Cities Where Detected[2] | Frequency of Detection[3] | Range of Detected Concentrations (μg/ℓ)[4] |
|---|---|---|---|
| I. PESTICIDES | | | |
| 1. Acrolein | Holding times exceeded | | |
| 2. Aldrin | 4,7,26 | 6 | 0.002T-0.1M |
| 3. α-Hexachlorocyclohexane (α-BHC) (Alpha) | 7,8,22,26 | 20 | 0.002T-0.1M |
| 4. β-Hexachlorocyclohexane (β-BHC) (Beta) | 7,8 | 5 | 0.018-0.1M |
| 5. γ-Hexachlorocyclohexane (γ-BHC) (Gamma) (Lindane) | 7,8,22,26 | 15 | 0.007-0.1M |
| 6. δ-Hexachlorocyclohexane (δ-BHC) (Delta) | 7,26 | 6 | 0.004-0.1M |
| 7. Chlordane | 2,8,21,26 | 17 | 0.01L-10 |
| 8. DDD | Not detected | | |
| 9. DDE | 26 | 6 | 0.007-0.027 |
| 10. DDT | 7 | 1 | 0.1M |
| 11. Dieldrin | 26,27 | 6 | 0.007-0.1 |
| 12. α-Endosulfan (Alpha) | 7,26,27 | 19 | 0.008-0.2 |
| 13. β-Endosulfan (Beta) | Not detected | | |
| 14. Endosulfan sulfate | Not detected | | |
| 15. Endrin | Not detected | | |
| 16. Endrin aldehyde | Not detected | | |
| 17. Heptachlor | 7,8,27 | 6 | 0.01-0.1M |
| 18. Heptachlor epoxide | 7,26 | 2 | 0.003T-0.1M |
| 19. Isophorone | 7 | 3 | 10M |
| 20. TCDD (2,3,7,8-tetrachlorodibenzo-p-dioxin) | Not included in NURP program | | |
| 21. Toxaphene | Not detected | | |
| II. METALS AND INORGANICS | | | |
| 22. Antimony | 7,24,26 | 13 | 2.6-23A |
| 23. Arsenic | 2,3,7,12,19,20,21,22,26,27 | 52 | 1-50.5 |
| 24. Asbestos | Not included in NURP program | | |
| 25. Beryllium | 7,12,20,21 | 12 | 1-49 |
| 26. Cadmium | 1,2,3,7,12,20,21,27 | 48 | 0.1M-14 |
| 27. Chromium | 1,2,7,8,12,17,19,20,21,22,26,27,28 | 58 | 1-190 |
| 28. Copper | 1,2,3,4,7,8,12,17,19,20,21,22,23,26,27,28 | 91 | 1L-100 |
| 29. Cyanides | 4,8,19,22,26,27 | 23 | 2-300 |
| 30. Lead | 1,2,3,4,7,8,12,17,19,20,21,22,26,28 | 94 | 6-460 |
| 31. Mercury | 7,20,28 | 9 | 0.6-1.2 |
| 32. Nickel | 2,3,7,12,20,21,26,27 | 43 | 1-182 |
| 33. Selenium | 7,19,23 | 11 | 2-77 |
| 34. Silver | 3,17,27 | 7 | 0.2M-0.8 |
| 35. Thallium | 7 | 6 | 1-14 |
| 36. Zinc | 1,2,3,7,12,17,19,20,21,22,23,27,28 | 94 | 10-2400 |
| III. PCBs AND RELATED COMPOUNDS | | | |
| 37. PCB-1016 (Aroclor 1016) | Not detected | | |
| 38. PCB-1221 (Aroclor 1221) | Not detected | | |
| 39. PCB-1232 (Aroclor 1232) | Not detected | | |
| 40. PCB-1242 (Aroclor 1242) | Not detected | | |
| 41. PCB-1248 (Aroclor 1248) | Not detected | | |
| 42. PCB-1254 (Aroclor 1254) | Not detected | | |
| 43. PCB-1260 (Aroclor 1260) | 2 | 1 | 0.03 |
| 44. 2-Chloronaphthalene | Not detected | | |

TABLE 6-19. SUMMARY OF ANALYTICAL CHEMISTRY FINDINGS FROM NURP PRIORITY POLLUTANT SAMPLES[1] (Cont'd)

(Includes information received through September 30, 1983)

| Pollutant | Cities Where Detected[2] | Frequency of Detection[3] | Range of Detected Concentrations (µg/l)[4] |
|---|---|---|---|
| IV. HALOGENATED ALIPHATICS | | | |
| 45. Methane, bromo- (methyl bromide) | Not detected | | |
| 46. Methane, chloro- (methyl chloride) | Not detected | | |
| 47. Methane, dichloro- (methylene chloride) | 4,17,22 | 11 | 5-14.5A |
| 48. Methane, chlorodibromo- | 28 | 1 | 2 |
| 49. Methane, dichlorobromo- | 28 | 1 | 2 |
| 50. Methane, tribromo - (bromoform) | 28 | 1 | 1 |
| 51. Methane, trichloro- (chloroform) | 4,17,20,22,23,27,28 | 9 | 0.2T-12E |
| 52. Methane, tetrachloro- (carbon tetrachloride) | 4,28 | 3 | 1-2 |
| 53. Methane, trichlorofluoro-[5] | 2,4,24,28 | 5 | 0.61-27 |
| 54. Methane, dichlorodifluoro- (Freon-12)[5] | Not detected | | |
| 55. Ethene, chloro- | Not detected | | |
| 56. Ethane, 1,1-dichloro- | 4,28 | 3 | 1.5A-3 |
| 57. Ethane, 1,2-dichloro- | 28 | 1 | 4 |
| 58. Ethane, 1,1,1-trichloro- | 4,2,7,22,24 | 6 | 1.6-30M |
| 59. Ethane, 1,1,2-trichloro- | 28 | 2 | 2-3 |
| 60. Ethane, 1,1,2,2-tetrachloro- | 4 | 2 | 20-3 |
| 61. Ethane, hexachloro- | Not detected | | |
| 62. Ethene, chloro- (vinyl chloride) | Not detected | | |
| 63. Ethene, 1,1-dichloro- | 28 | 2 | 1.5-4 |
| 64. Ethene, 1,2-trans-dichloro- | 20,28 | 4 | 1-3 |
| 65. Ethene, trichloro- | 2,4,8,24,28 | 6 | 0.3T-12 |
| 66. Ethene, tetrachloro- | 8,17,22,28 | 5 | 19-43 |
| 67. Propane, 1,2-dichloro- | 28 | 1 | 3 |
| 68. Propene, 1,3-dichloro- | 28 | 2 | 1-2 |
| 69. Butadiene, hexachloro- | Not detected | | |
| 70. Cyclopentadiene, hexachloro- | Standard methods inappropriate | | |
| V. ETHERS | | | |
| 71. Ether, bis(chloromethyl)[5] | Not detected | | |
| 72. Ether, bis(2-chloroethyl) | Not detected | | |
| 73. Ether, bis(2-chloroisopropyl) | Not detected | | |
| 74. Ether, 2-chloroethyl vinyl | Not detected | | |
| 75. Ether, 4-bromophenyl phenyl | Not detected | | |
| 76. Ether, 4-chlorophenyl phenyl | Not detected | | |
| 77. Bis(2-chloroethoxy) methane | Not detected | | |
| VI. MONOCYCLIC AROMATICS (EXCLUDING PHENOLS, CRESOLS, PHTHALATES) | | | |
| 78. Benzene | 4,17,27 | 5 | 1-13 |
| 79. Benzene, chloro- | 7,20,26,28 | 5 | 10-10M |
| 80. Benzene, 1,2-dichloro- | Not detected | | |
| 81. Benzene, 1,3-dichloro- | Not detected | | |
| 82. Benzene, 1,4-dichloro- | Not detected | | |
| 83. Benzene, 1,2,4-trichloro- | Not detected | | |
| 84. Benzene, hexachloro- | Not detected | | |
| 85. Benzene, ethyl- | 4,8,17,20,26,28 | 6 | 1-7 |
| 86. Benzene, nitro- | Not detected | | |
| 87. Toluene | 4,17 | 3 | 3-9 |
| 88. Toluene, 2,4-dinitro- | Not detected | | |
| 89. Toluene, 2,6-dinitro | Not detected | | |

TABLE 6-19. SUMMARY OF ANALYTICAL CHEMISTRY FINDINGS FROM NURP PRIORITY POLLUTANT SAMPLES[1] (Cont'd)

(Includes information received through September 30, 1983)

| Pollutant | Cities Where Detected[2] | Frequency of Detection[3] | Range of Detected Concentrations (μg/l)[4] |
|---|---|---|---|
| VII. PHENOLS AND CRESOLS | | | |
| 90. Phenol | 4,7,26 | 14 | 11-15T |
| 91. Phenol, 2-chloro- | 28 | 1 | 2 |
| 92. Phenol, 2,4-dichloro- | Not detected | | |
| 93. Phenol, 2,4,6-trichloro- | Not detected | | |
| 94. Phenol, pentachloro- | 4,8,19,20,26,27,28 | 19 | 1T-115 |
| 95. Phenol, 2-nitro- | 8 | 1 | 1M |
| 96. Phenol, 4-nitro- | 4,7,8,20,26,28 | 16 | 1T-37 |
| 97. Phenol, 2,4-dinitro- | Not detected | | |
| 98. Phenol, 2,4-dimethyl- | 4,7,8,26 | 8 | 1T-10M |
| 99. m-Cresol, p-chloro- | 4 | 1 | 1.5A |
| 100. o-Cresol 4,6-dinitro- | Not detected | | |
| VIII. PHTHALATE ESTERS | | | |
| 101. Phthalate, dimethyl | 8 | 1 | 1L |
| 102. Phthalate, diethyl | 3,4,17,20,21 | 6 | 1-10M |
| 103. Phthalate, di-n-butyl | 4,22,24 | 6 | 0.5T-11 |
| 104. Phthalate, di-n-octyl | 8,20,26,27,28 | 6 | 0.4T-20 |
| 105. Phthalate, bis(2-ethylhexyl) | 4,12,14,22,21,28 | 22 | 47-62 |
| 106. Phthalate, butyl benzyl | 2,8,26 | 6 | 1-10M |
| IX. POLYCYCLIC AROMATIC HYDROCARBONS | | | |
| 107. Acenaphthene | Not detected | | |
| 108. Acenaphthylene | Not detected | | |
| 109. Anthracene | 2,17,20,21,26,28 | 7 | 1-10M |
| 110. Benzo (a) anthracene | 2,21,27 | 4 | 1-10M |
| 111. Benzo (b) fluoranthene | 26,27 | 5 | 1-5 |
| 112. Benzo (k) fluoranthene | 2,21,27 | 3 | 4-14 |
| 113. Benzo (g,h,i) perylene | 21 | 1 | 5 |
| 114. Benzo (a) pyrene | 2,21,26,27 | 6 | 1-10M |
| 115. Chrysene | 2,7,17,21,26,27 | 10 | 0.67-10M |
| 116. Dibenzo (a,h) anthracene | 21 | 1 | 1T |
| 117. Fluoranthene | 2,8,12,17,21,26,27,28 | 16 | 0.3T-21 |
| 118. Fluorene | 20 | 1 | 1 |
| 119. Indeno (1,2,3-c,d) pyrene | 21 | 1 | 4 |
| 120. Naphthalene | 4,24,26,28 | 9 | 0.6T-2.5 |
| 121. Phenanthrene | 2,8,17,20,21,26,27,28 | 12 | 0.3T-10M |
| 122. Pyrene | 2,3,8,12,17,21,26,27,28 | 15 | 0.3T-16 |

TABLE 6-19. SUMMARY OF ANALYTICAL CHEMISTRY FINDINGS FROM NURP PRIORITY POLLUTANT SAMPLES[1] (Cont'd)

(Includes information received through September 30, 1983)

| Pollutant | Cities Where Detected[2] | Frequency of Detection[3] | Range of Detected Concentrations (µg/ℓ)[4] |
|---|---|---|---|
| X. NITROSAMINES AND OTHER NITROGEN-CONTAINING COMPOUNDS | | | |
| 123. Nitrosamine, dimethyl (DMN) | Standard methods inappropriate | | |
| 124. Nitrosamine, diphenyl | Standard methods inappropriate | | |
| 125. Nitrosamine, di-n-propyl | Not detected | | |
| 126. Benzidine | Standard methods inappropriate | | |
| 127. Benzidine, 3,3'-dichloro- | Nnt detected | | |
| 128. Hydrazine, 1,2-diphenyl- | Standard methods inappropriate | | |
| 129. Acrylonitrile | Holding times exceeded | | |

[1] Based on 121 sample results received as of 9/30/83, adjusted for quality control review.

[2] Cities from which data are available:

1. Durham, NH
2. Lake Quinsigamond, MA
3. Mystic River, MA
4. Long Island, NY
7. Washington, DC
8. Baltimore, MD
12. Knoxville, TN
17. Glen Ellyn, IL
19. Austin, TX
20. Little Rock, AR
21. Kansas City, KS
22. Denver, CO
23. Salt Lake City, UT
24. Rapid City, SD
26. Fresno, CA
27. Bellevue, WA
28. Eugene, OR

Numbering of cities conforms to NURP convention.

[3] Percentages rounded to nearest whole number.

[4] Some reported concentrations are qualified by STORET quality control remark codes, to wit: A = Value reported is the mean of two or more determinations; G = Value reported is the maximum of two or more determinations; L = Actual value is known to be greater than value given; M = Presence of material verified but not quantified; T = Value reported is less than criteria of detection. One value in this column indicates one positive observation or that all observations were equal.

[5] No longer included as a priority pollutant.

TABLE 6-20. MOST FREQUENTLY DETECTED PRIORITY POLLUTANTS IN NURP URBAN RUNOFF SAMPLES[1]

Priority Pollutants Detected in 75 Percent or More of the NURP Samples

| Inorganics | Organics |
|---|---|
| 30. Lead (94%) | None |
| 36. Zinc (94%) | |
| 28. Copper (91%) | |

Priority Pollutants Detected in 50 percent to 74 percent of the NURP Samples

| Inorganics | Organics |
|---|---|
| 27. Chrominum (58%) | None |
| 23. Arsenic (52%) | |

Priority Pollutants Detected in 20 percent to 49 percent of the NURP Samples

| Inorganics | Organics |
|---|---|
| 26. Cadmium (48%) | 105. Bis(2-ethylhexyl) phthalate (22%) |
| 32. Nickel (43%) | 3. α-Hexachlorocyclohexane (20%) |
| 29. Cyanides (23%) | |

Priority Pollutants Detected in 10 percent to 19 percent of the NURP Samples

| Inorganics | Organics |
|---|---|
| 22. Antimony (13%) | 12. α-Endosulfan (19%) |
| 25. Beryllium (12%) | 94. Pentachlorophenol (19%) |
| 33. Selenium (11%) | 7. Chlordane (17%) |
| | 5. γ-Hexachlorocyclohexane (Lindane) (15%) |
| | 122. Pyrene (15%) |
| | 90. Phenol (14%) |
| | 121. Phenanthrene (12%) |
| | 47. Dichloromethane (methylene chloride) (11%) |
| | 96. 4-Nitrophenol (10%) |
| | 115. Chrysene (10%) |
| | 117. Fluoranthene (16%) |

[1] Based on 121 sample results received as of September 30, 1983, adjusted for quality control review. Does not include special metals samples.

metals project in order to determine the relationships among dissolved, total, and total recoverable concentrations. The discussion and result of this separate effort are in a subsequent section of this chapter.

A comparison of individual urban runoff sample concentrations undiluted by stream flow (i.e., end of pipe concentrations) with EPA water quality criteria and drinking water standards reveals numerous exceedances of these levels, as shown in Table 6-21. Freshwater acute criteria were exceeded by copper concentrations in 47 percent of the samples and by lead in 23 percent. Freshwater chronic exceedances were common for lead (94 percent), copper (82 percent), zinc (77 percent), and cadmium (48 percent). One organ oleptic (taste and odor) criteria exceedance was observed. Regarding human toxicity, the most significant pollutant was lead. Lead concentrations violated drinking water criteria in 73 percent of the observations.

Whenever an exceedance is noted above, it does not necessarily imply that an actual violation of criteria did or will take place in receiving waters. Rather, the enumeration of exceedances is used as a screening procedure to make a preliminary identification of those pollutants for which their presence in urban runoff requires highest priority for further evaluation. Exceedances of freshwater chronic criteria levels may not persist for a full 24-hour period, for example. However, many small urban streams probably carry only slightly diluted runoff following storms, and acute criteria or other exceedances may in fact be real in such circumstances.

Among the inorganics, the most frequently detected pollutants are also those which are found at the highest concentrations, which most frequently exceed water quality criteria and which are the most geographically well-distributed. One additional observation can be made concerning the samples from Washington, D.C. These samples accounted for a preponderance of the detections of many of the less frequently detected inorganics, including antimony, beryllium, mercury, nickel, selenium, and thallium. No sampling or analytical irregularities have been identified which explain this result.

Organic Pollutants. In general, the organic pollutants were detected less frequently and at lower concentrations than the inorganic pollutants. Sixty-three of a possible 106 organics were detected. The most commonly found organic was the plasticizer bis (2-ethylhexyl) phthalate (22 percent) followed by the pesticide α-hexachlorocyclohexane (α-BHC) (20 percent). An additional 11 organic pollutants were reported with detection frequencies between 10 and 20 percent; 3 pesticides, 3 phenols, 4 polycyclic aromatics, and a single haloginated aliphatic (Table 6-20).

Criteria exceedances were less frequently observed among the organics than the inorganics. One unusually high pentachlorophenol concentration of 115 μg/l resulted in the only exceedance of the organoleptic criteria (Table 6-21). This observation and one for the chlordane exceeded the freshwater acute criteria. Freshwater chronic criteria exceedances were observed for pentochlorophenol, bis (2-ethylhexyl) phthalate, γ-hexachlorocyclohexane (Lindane), α-endosulfan, and chlordane. All other organic exceedances were in the human carcinogen category and were most serious for α-hexachlorocyclohexane (α-BHC), γ-hexachlorocyclohexane (γ-BHC or Lindane), chlordane, phenanthrene, pyrene, and chrysene.

TABLE 6-21. SUMMARY OF WATER QUALITY CRITERIA EXCEEDANCES FOR POLLUTANTS DETECTED IN AT LEAST 10 PERCENT OF NURP SAMPLES: PERCENTAGE OF SAMPLES IN WHICH POLLUTANT CONCENTRATIONS EXCEED CRITERIA[1]

| Pollutant | Frequency of Detection (%) | Detections/ Samples[2] | Criteria Exceedances (%)[3] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | None | FA | FC | TO | HH | HC[4] | DW |
| I. PESTICIDES | | | | | | | | | |
| 3. α-Hexachlorocyclohexane | 20 | 21/106 | | | | | | 8,18,20 | |
| 5. γ-Hexachlorocyclohexane (Lindane) | 15 | 15/100 | | | 8 | | | 0,10,15 | |
| 7. Chlordane | 17 | 7/42 | | 2 | 17 | | | 17,17,17 | |
| 12. α-Endosulfan | 19 | 9/49 | | | 19 | | | | |
| II. METALS AND INORGANICS | | | | | | | | | |
| 22. Antimony | 13 | 14/106 | X | | | | | | |
| 23. Arsenic | 52 | 45/87 | | | | | | 52,52,52 | 1 |
| 25. Beryllium | 12 | 11/94 | | | 6* | | | 12,12,12 | |
| 26. Cadmium[5] | 48 | 44/91 | | 8 | 48 | | 1 | | 1 |
| 27. Chromium[5,6] | 58 | 47/81 | | | 1* | | | | 1 |
| 28. Copper[5] | 91 | 79/87 | | 47 | 82 | | | | |
| 29. Cyanides | 23 | 16/71 | | 3 | 22 | | 4 | | |
| 30. Lead[5] | 94 | 75/80 | | 23 | 94 | | 73 | | 73 |
| 32. Nickel[5] | 43 | 39/91 | | | 5 | | 21 | | |
| 33. Selenium | 11 | 10/88 | | | 5 | | 10 | | 10 |
| 36. Zinc[5] | 94 | 88/94 | | 14 | 17 | | | | |
| IV. HALOGENATED ALIPHATICS | | | | | | | | | |
| 47. Methane, dichloro- | 11 | 3/28 | | | | | | 0,0,11 | |
| VII. PHENOLS AND CRESOLS | | | | | | | | | |
| 90. Phenol | 14 | 13/91 | X | | | | | | |
| 94. Phenol, pentachloro- | 19 | 21/111 | | 1* | 11* | 1 | | | |
| 96. Phenol, 4-nitro- | 10 | 11/107 | X | | | | | | |
| VIII. PHTHALATE ESTERS | | | | | | | | | |
| 105. Phthalate, bis(2-ethylhexyl) | 22 | 15/69 | | | 22* | | | | |
| IX. POLYCYCLIC AROMATIC HYDROCARBONS | | | | | | | | | |
| 115. Chrysene | 10 | 11/109 | | | | | | 10,10,10 | |
| 117. Fluoranthene | 16 | 17/109 | X | | | | | | |
| 121. Phenanthrene | 12 | 13/110 | | | | | | 12,12,12 | |
| 122. Pyrene | 15 | 16/110 | | | | | | 15,15,15 | |

* Indicates FTA or FTC value substituted where FA or FC criterion not available (see below).

[1] Based on 121 sample results received as of September 30, 1983, adjusted for quality control review.

[2] Number of times detected/number of acceptable samples.

[3] FA = Freshwater ambient 24-hour instantaneous maximum criterion ("acute" criterion).
FC = Freshwater ambient 24-hour average criterion ("chronic" criterion).
FTA = Lowest reported freshwater acute toxic concentration. (Used only when FA is not available.)
FTC = Lowest reported freshwater chronic toxic concentration. (Used only when FC is not available.)
TO = Taste and odor (organoleptic) criterion.
HH = Non-Carcinogenic human health criterion for ingestion of contaminated water and organisms.
HC = Protection of human health from carcinogenic effects for ingestion of contaminated water and organisms.
DW = Primary drinking water criterion.

[4] Entries in this column indicate exceedances of the human carcinogen value at the $10^{-5}$, $10^{-6}$, and $10^{-7}$ risk level, respectively. The numbers are cumulative, i.e., all $10^{-5}$ exceedances are included in $10^{-6}$ exceedances, and all $10^{-6}$ exceedances are included in $10^{-7}$ exceedances.

[5] Where hardness dependent, hardness of 100 mg/l $CaCO_3$ equivalent assumed.

[6] Different criteria are written for the trivalent and hexavalent forms of chromium. For purposes of this analysis, all chromium is assumed to be in the less toxic trivalent form.

An additional 50 organic pollutants were found in one to nine percent of the samples. These frequencies of detection are low, and the pollutant is noted in Table 6-22.

Among the PCB group, there was only a single detection of one PCB type among all the samples. Approximately two-thirds of the halogenated aliphatic compounds were detected. Among those cities reporting these compounds, the city of Eugene, Oregon, figured prominently. For example, eight pollutants from this group were found in Eugene only. None of the pollutants in the ethers group were detected.

Monocyclic aromatics were rarely detected in the samples. However, many reported detections of benzene and toluene, two commonly reported pollutants, had to be withdrawn due to contamination problems.

Of the 11 phenolics, four have not been reported in urban runoff, while three have been observed only once. The remaining four have been found fairly frequently but at low concentrations. Exceedances of criteria were noted only for pentachlorophenol.

All the phthalate esters were detected at least once in the NURP program, with bis (2-ethylhexyl) found most frequently. Several times the reported concentration exceeded the lowest observed freshwater acute toxic concentration for this pollutant. Given the significant blank contamination problems with the phthalates, however, these findings must be interpreted with caution.

Only two of the polycyclic aromatic hydrocarbons were not detected in at least one sample. Crysene, phenanthrene, pyrene, and fluoranthene were each found at least 10 percent of the time. All the observed concentrations for the first three of these pollutants exceeded the criteria for the protection of human health from carcinogenic effects (there are no such criteria for fluoranthene). Results for the polycyclic aromatics were generally free from quality control problems.

There were no detections of nitrosamines or other nitrogen-containing compounds. Due to methodological and holding time problems, however, results for only two compounds can be used. Moreover, for one of these compounds, 3,3-dichlorobenzidine, performance evaluation results were unacceptable in several cases.

<u>Pollutants Not Detected In Urban Runoff</u>

Some 43 priority pollutants were not detected in any acceptable runoff samples (Table 6-22). All of these pollutants are organics. This group of substances should be considered to pose a minimal threat to the quality of surface waters from runoff contamination.

While the priority pollutants which were not detected are of less immediate concern than those pollutants found often, they cannot safely be eliminated from all future consideration. Many of these pollutants have associated water quality criteria which are below the limits of detection of routine

TABLE 6-22. INFREQUENTLY DETECTED ORGANIC PRIORITY POLLUTANTS IN NURP URBAN RUNOFF SAMPLES[1]

Priority Pollutants Detected in 1 percent to 9 percent of the NURP Samples

51. Trichloromethane (9%)
120. Naphthalene (9%)
98. 2,4-Dimethyl phenol (8%)
109. Anthracene (7%)
2. Aldrin (6%)
6. δ-Hexachlorocyclohexane (6%)
9. DDE (6%)
11. Dieldrin (6%)
17. Heptachlor (6%)
58. 1,1,1-Trichloroethane (6%)
65. Trichloroethene (6%)
85. Ethylbenzene (6%)
102. Diethyl phthalate (6%)
103. Di-n-butyl phthalate (6%)
104. Di-n-octyl phthalate (6%)
106. Butyl benzyl phthalate (6%)*
114. Benzo(a)pyrene (6%)
4. β-Hexachlorocyclohexane (5%)
53. Trichlorofluoromethane (5%)[2]
66. Tetrachloroethene (5%)
78. Benzene (5%)
79. Chlorobenzene (5%)
111. Benzo(b)fluoranthene (5%)*
64. 1,2-trans-dichloroethene (4%)
110. Benzo(a)anthracene (4%)
19. Isophorone (3%)
52. Tetrachloromethane (carbon tetrachloride) (3%)
56. 1,1-Dichloroethane (3%)
87. Toluene (3%)
112. Benzo(k)fluoranthene (3%)
18. Heptachlor epoxide (2%)*
59. 1,1,2-Trichloroethane (2%)*
60. 1,1,2,2-Tetrachloroethane (2%)*
63. 1,1-Dichloroethene (2%)
68. 1,3-Dichloropropene (2%)*
113. Benzo(g,h,i)perylene (2%)
10. DDT (1%)*
43. PCB-1260 (1%)*
48. Chlorodibromomethane (1%)*
49. Dichlorobromomethane (1%)*
50. Tribromomethane (bromoform) (1%)*
57. 1,2-Dichloroethane (1%)*
67. 1,2-Dichloropropane (1%)*
91. 2-Chlorophenol (1%)*
95. 2-Nitrophenol (1%)*
99. p-Chloro-m-creosol (1%)*
101. Dimethyl phthalate (1%)*
116. Dibenzo(a,h)anthracene (1%)*
118. Fluorene (1%)*
119. Indeno(1,2,3-cd)pyrene (1%)*

TABLE 6-22. INFREQUENTLY DETECTED ORGANIC PRIORITY POLLUTANTS IN NURP URBAN RUNOFF SAMPLES[1] (Cont'd)

Priority Pollutants Not Detected in NURP Samples

8. DDD
13. β-Endosulfan
14. Endosulfan sulfate
15. Endrin
16. Endrin aldehyde
21. Toxaphene
37. PCB-1016
38. PCB-1221
39. PCP-1232
40. PCB-1242
41. PCB-1248
42. PCB-1254
44. 2-Chloronaphthalene
45. Bromomethane (methyl bromide)
46. Chloromethane (methyl chloride)
54. Dichlorodifluoromethane (Freon-12)[2]
55. Chloroethane
61. Hexachloroethane
62. Chloroethene (vinyl chloride)
69. Hexachlorobutadiene
71. Bis(chloromethyl) ether[2]
72. Bis(chloroethyl) ether
73. Bis(chloroisopropyl) ether
74. 2-Chloroethyl vinyl ether
75. 4-Bromophenyl phenyl ether
76. 4-Chlorophenyl phenyl ether
77. Bis(2-chloroethoxy) methane
80. 1,2-Dichlorobenzene
81. 1,3-Dichlorobenzene
82. 1,4-Dichlorobenzene
83. 1,2,4-Trichlorobenzene
84. Hexachlorobenzene
86. Nitrobenzene
88. 2,4-Dinitrotoluene
89. 2,6-Dinitrotoluene
92. 2,4-Dichlorophenol
93. 2,4,6-Trichlorophenol
97. 2,4-Dinitrophenol
100. 4,6-Dinitro-o-cresol
107. Acenaphthene
108. Acenaphthylene
125. Di-n-propyl nitrosamine
127. 3,3'-Dichlorobenzidine

TABLE 6-22. INFREQUENTLY DETECTED ORGANIC PRIORITY POLLUTANTS IN NURP URBAN RUNOFF SAMPLES[1] (Cont'd)

Priority Pollutants Not Analyzed for or Withdrawn for Methodological Reasons or Holding Time Violations

1. Acrolein
20. TCDD (Dioxin)
24. Asbestos
70. Hexachlorocyclopentadiene
123. Dimethyl nitrosamine (DMN)
124. Diphenyl nitrosamine
126. Benzidine
128. 1,2-Diphenyl hydrazine
129. Acrylonitrile

* Detected in only one or two samples.

1 Based on 121 sample results received as of September 30, 1983, adjusted for quality control review.

2 No longer on the priority pollutant list.

analytical methods. Some of these substances may in fact have been present in the NURP samples. Four priority pollutants not detected in runoff were found in street dust sweepings from Bellevue, Washington, suggesting that further urban runoff samplings can be expected to detect more priority pollutants. More sensitive analytical methodologies must be used and dilution effects considered before it can be said with assurance that these pollutants are not found in urban stormwater runoff at levels which, without dilution, pose a threat to human health or aquatic life.

DDD, chloromethane, 1,2-dichlorobenzene, and 2,4-dichlorophenol were detected in runoff samples at least once, but these observations had to be withdrawn for quality control reasons. Therefore, among the not detected pollutants, these four can be considered to have a slightly elevated possibility of actually being present in the runoff samples.

RUNOFF-RAINFALL RELATIONSHIPS

A runoff coefficient (Rv), defined as the ratio of runoff volume to rainfall volume, has been determined for each of the monitored storm events. As with the EMCs, the runoff coefficient values at a particular site are, with relatively few exceptions, well characterized by a lognormal distribution. Table 6-23 summarizes the statistical properties of Rv's at the loading sites in the data base.

Figure 6-19 illustrates the relationship between percent impervious area and the median runoff coefficient for the site. Sites which monitored fewer than 5 storms are excluded. The upper plot (a) groups the results from 16 of the

# TABLE 6-23. RUNOFF COEFFICIENTS FOR LAND USE SITES

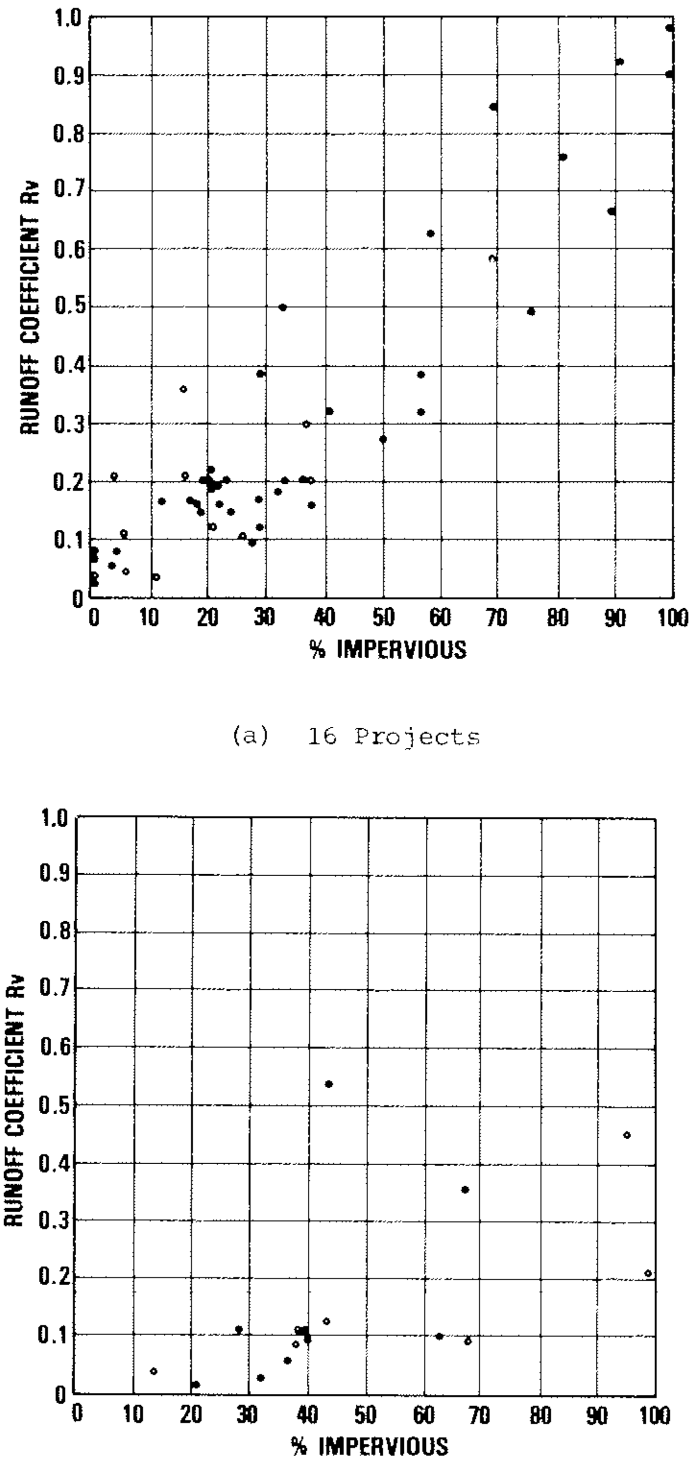
| | Residential | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Site | Land Use % Res | No. of Events | Drainage Area (Ac) | Population Density (Pers/Acre) | Imperv | Runoff Coef (Rv) Median | Coef Var |
| 1 | CO1 Big Dry Cr | 100 | 36 | 33 | 19 | [illegible] | [illegible] | .27 |
| 2 | CO1 Cherry | 100 | 25 | [illegible] | 24 | 36 | [illegible] | .35 |
| 3 | DC1 Glen Claude | 100 | 24 | 102 | 14 | [illegible] | [illegible] | 4 |
| 4 | CO1 Gullet | 100 | 57 | 17 | 2 | 19 | .06 | [illegible] |
| 5 | NC1 Coleridge | 100 | 49 | 68 | 1 | [illegible] | .13 | [illegible] |
| 6 | NC1 Stratton | 100 | 31 | 2 | [illegible] | [illegible] | [illegible] | .92 |
| 7 | SL1 Lodge Apt | 100 | 17 | 5 | - | - | .05 | .64 |
| 8 | IL1 John N | 100 | 27 | 53 | 15 | 19 | .13 | [illegible] |
| 9 | LS1 Overlan | 100 | 11 | 58 | 9 | 18 | .08 | .11 |
| 10 | MA2 Seldon | 100 | 6 | 50 | 5 | 16 | .15 | .16 |
| 11 | MD1 Rufton Hill | 100 | 15 | 14 | 30 | 11 | .44 | [illegible] |
| 12 | MD1 Homeland | 100 | 25 | 29 | 9 | 29 | .1L | [illegible] |
| 13 | MD1 Mt Wash | 100 | 20 | 17 | 12 | 29 | .14 | 1.25 |
| 14 | MD1 Res Hill | 100 | 11 | 10 | 55 | 26 | .41 | .54 |
| 15 | MI1 Carll's W. | 100 | 29 | 73 | 13 | 20 | .22 | .51 |
| 16 | NI2 Grinslon | 100 | 11 | 166 | 5 | 27 | .18 | .35 |
| 17 | NI2 Ex Lgch | 100 | 9 | 146 | 1M | 35 | .20 | .42 |
| 18 | TX1 Rollingwood | 100 | 9 | 60 | 3 | 37 | .02 | .29 |
| 19 | WA1 Surrey | 100 | 139 | 95 | 9 | 29 | .12 | .56 |
| 20 | WI1 Burbank | 100 | 44 | 13 | 15 | 50 | .17 | .97 |
| 21 | WI1 Hastings | 100 | 33 | 33 | 17 | 51 | .27 | .37 |
| 22 | IL1 Hart | 96 | 34 | 175 | N | 40 | .09 | .96 |
| 23 | WI1 Lincoln | 97 | 39 | 30 | 10 | 57 | .21 | .52 |
| 24 | TN1 I7 | 96 | 11 | 89 | 4 | 13 | .01 | .67 |
| 25 | NC1 Westlight | 95 | 19 | 41 | 3 | 21 | .12 | 1.15 |
| 26 | NY1 CC - Ainl | 92 | 14 | 61 | - | 27 | .05 | 1.09 |
| 27 | IL1 John S. | 91 | 29 | 39 | 18 | 12 | .17 | .54 |
| 28 | TN1 R1 | 91 | 9 | 99 | 11 | 32 | .01 | .98 |
| 29 | WA1 Lake Hills | 91 | 11 | 102 | 12 | 37 | .20 | .41 |
| 30 | IL1 Martin S | 90 | 20 | 25 | 22 | 27 | .13 | .16 |
| 31 | FL1 Charter M. | 89 | 11 | 42 | - | 36 | .05 | 4.55 |
| 32 | GL1 Lakeside | 38 | 44 | 13 | - | 34 | .15 | 1.32 |
| 33 | CO1 Asbury | 86 | 16 | 127 | 9 | [illegible] | .19 | .92 |
| 34 | IL1 Cook Islets | 86 | 29 | 574 | 8 | 11 | .17 | .48 |
| 35 | MO1 Locust | 85 | 6 | 158 | 11 | 16 | .21 | .33 |
| 36 | NC1 #3022 | 84 | 63 | 324 | 1 | [illegible] | [illegible] | .47 |
| 37 | MA1 Jordan | 79 | 9 | 111 | 10 | 21 | [illegible] | .55 |
| 38 | OC1 Sledwell | 72 | 45 | [illegible] | 15 | 14 | .20 | 1.07 |

| | Urban Open and Nonurban | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Site | Land Use % Open | No. of Events | Drainage Area (Ac) | Population Density (Pers/Acre) | Imperv | Runoff Coef (Rv) Median | Coef Var |
| [illegible] | CO1 Sernline | 100 | [illegible] | 553 | - | 1 | .03 | 5.86 |
| [illegible] | CO1 Powers Gulch | [illegible] | | 106 | - | 1 | .14 | 2.04 |
| [illegible] | NY1 Unqua | 100 | 13 | 24,031 | - | 3 | .06 | .97 |
| 4 | NY1 Smith Br | 98 | 9 | 1,442 | - | 1 | .04 | 1.23 |
| [illegible] | NY1 West Br | [illegible] | [illegible] | 6,336 | - | 1 | .07 | .11 |
| [illegible] | NY1 Tamaqua Cr | [illegible] | 15 | 17,225 | 1 | [illegible] | .04 | .66 |
| [illegible] | MI1 Teleg. | [illegible] | [illegible] | 1,17 | | 6 | .1 | [illegible] |
| [illegible] | NY1 Swan Cr | [illegible] | 1 | [illegible] | | | .15 | 1.25 |

| | Mixed | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Site | Land Use | No. of Events | Drainage Area (Ac) | Population Density (Pers/Acre) | Imperv | Runoff Coef (Rv) Median | Coef Var |
| 1 | AS1 Holland | - | 25 | 38 | 3 | 65 | .09 | 1.04 |
| 2 | IN1 Damaier | - | 22 | [illegible] | 40 | 72 | .29 | .51 |
| 3 | IL1 Martin N | - | 26 | 17 | [illegible] | 56 | .64 | .57 |
| 4 | MO1 Waverly | - | 35 | 32 | 11 | 68 | .06 | .25 |
| 5 | TN1 C1 | - | 12 | 157 | 3 | 45 | .14 | .46 |
| 6 | WI1 Wild Flr | - | 44 | 45 | 14 | 51 | .26 | .42 |
| 7 | MA1 Fl 1 | - | [illegible] | 532 | [illegible] | 31 | .20 | .99 |
| 8 | MA1 Conant | - | 6 | 105 | 1 | 37 | .50 | .36 |
| 9 | MI1 Grand W Dr | - | 33 | 453 | 5 | 36 | .31 | .60 |
| 10 | IL1 Wilgen | - | 15 | 194 | - | - | .01 | 1.12 |
| 11 | MI1 Pitt AA-S | - | 6 | 2001 | - | 31 | .29 | .41 |
| 12 | NI1 Cedar | - | 12 | 76 | - | 6 | .08 | 1.05 |
| 13 | IL1 Jesuit | - | 15 | 30 | - | 12 | .32 | 1.03 |
| 14 | MA1 Anna | - | 6 | 603 | 9 | 12 | .17 | 1.64 |
| 15 | MI1 Pitt AA-N | - | 6 | 2671 | 7 | 26 | .10 | .43 |
| 16 | MI1 Grove h | - | 23 | 164 | 5 | 26 | .11 | .41 |
| 17 | IL1 Swift Tur | - | 5 | 1107 | 1 | 4 | .21 | .18 |
| 18 | SD1 Meade | - | 16 | 2000 | - | - | .10 | .57 |
| 19 | CA1 Knox | - | 42 | 1690 | 12 | - | .20 | .71 |
| 20 | CO1 North Ave | - | 33 | 19 | 1 | 50 | .24 | .59 |

| | Commercial | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Site | Land Use % Com | No. of Events | Drainage Area (Acs) | Population Density (Pers/Acre) | Imperv | Runoff Coef (Rv) Median | Coef Var |
| 1 | TX1 Villa Italia | 100 | 23 | 14 | 0 | 91 | .93 | .45 |
| 2 | NC1 1912 (CBD) | 100 | 112 | 23 | 0 | 69 | .79 | .49 |
| 3 | NI3 Southgate | 100 | 12 | 179 | 2 | 21 | .20 | .28 |
| 4 | WI1 Post Office | 100 | 54 | 12 | 0 | 100 | .90 | .19 |
| 5 | MI1 Rustler | 100 | 39 | 12 | 0 | 100 | .79 | .19 |
| 6 | NP1 Pkg Lot | 100 | 14 | 1 | 0 | 90 | .96 | .50 |
| 7 | TN1 CPP | 100 | 14 | 31 | 0 | 99 | .33 | .41 |
| 8 | LS1 CC Metrplx | 96 | 21 | 62 | - | 97 | .46 | .55 |
| 9 | TX1 Norma Park | 93 | 12 | 47 | - | 85 | .48 | .86 |
| 10 | WI1 State Fair | 74 | 21 | 29 | 10 | 77 | .62 | .24 |

| | Industrial | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Site | Land Use % Ind | No. of Events | Drainage Area (Acs) | Population Density (Pers/Acre) | Imperv | Runoff Coef (Rv) Median | Coef Var |
| 1 | MD1 Addison | 100 | 6 | 38 | 0 | 69 | .50 | .53 |
| 2 | NI1 Indus Lrng | 100 | 18 | 61 | 0 | 64 | .16 | .71 |
| 3 | AJ1 Lenox | 59 | 15 | 72 | [illegible] | 44 | .54 | .37 |
| 4 | MI1 Rouge 2 | 52 | 20 | 5 | 5 | 39 | .13 | .43 |




(a) 16 Projects

(b) 4 Projects (KS1, MI1, TN1, TX1)

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Figure 6-19. Relationship Between Percent Impervious Area and Median Runoff Coefficient

20 projects investigated. The lower plot (b) groups results from the remaining four projects (KS1, MI1, TN1, TX1). The reason for the difference is unexplained. However, the separate grouping is based on the fact that the relationship for these sites is internally consistent and significantly different than the bulk of the project results.

Figure 6-20 illustrates the same impervious area/runoff coefficient relationship, but shows the 90 percent confidence limits for median Rv's.

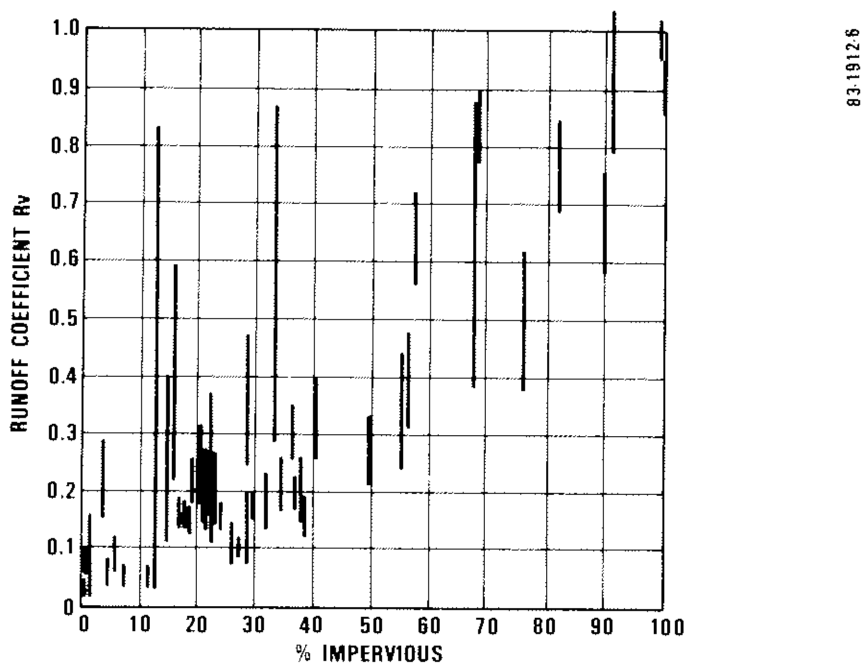
POLLUTANT LOADS

Although the EMC median concentration values are appropriate for many applications (e.g., assessing water quality impacts in rivers and streams), when cumulative effects such as water quality impacts in lakes and comparisons with other sources on a long-term basis (e.g., annual or seasonal loads) are to be examined, the EMC mean concentration values should be used. Taking the EMC median and coefficient of variation values given in Table 6-17, we have converted them into mean values using the relationship given in Chapter 5. These EMC mean concentrations and the values used in the load comparison to follow are listed in Table 6-24.

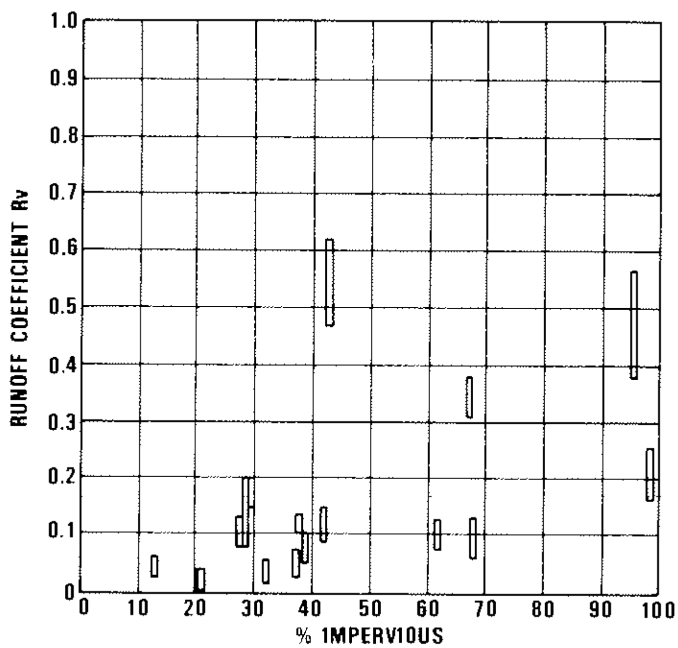
The range shown for site mean concentrations for both the median and 90th percentile urban sites reflects the difference in means depending on whether the higher or lower value of coefficient of variation listed in Table 6-17 is used to describe event-to-event variability of EMC's at urban sites. The range in values shown for use in the load comparisons below reflects the median and 90th percentile site mean concentrations, using the average of the range caused by coefficient of variation effects.

TABLE 6-24. EMC MEAN VALUES USED IN LOAD COMPARISON

| Constituent | Site Mean EMC | | |
|---|---|---|---|
| | Median Urban Site | 90th Percentile Urban Site | Values Used in Load Comparison |
| TSS (mg/l) | 141 - 224 | 424 - 671 | 180 - 548 |
| BOD (mg/l) | 10 - 13 | 17 - 21 | 12 - 19 |
| COD (mg/l) | 73 - 92 | 157 - 198 | 82 - 178 |
| Tot. P (mg/l) | 0.37 - 0.47 | 0.78 - 0.99 | 0.42 - 0.88 |
| Sol. P (mg/l) | 0.13 - 0.17 | 0.23 - 0.30 | 0.15 - 0.28 |
| TKN (mg/l) | 1.68 - 2.12 | 3.69 - 4.67 | 1.90 - 4.18 |
| $NO_{2+3}$-N (mg/l) | 0.76 - 0.96 | 1.96 - 2.47 | 0.86 - 2.21 |
| Tot. Cu (μg/l) | 38 - 48 | 104 - 132 | 43 - 118 |
| Tot. Pb (μg/l) | 161 - 204 | 391 - 495 | 182 - 443 |
| Tot. Zn (μg/l) | 179 - 226 | 559 - 707 | 202 - 633 |




(a) 16 Projects




(b) 4 Projects (KS1, MI1, TN1, TK1)

Figure 6-20. 90 Percent Confidence Limits for Median Runoff Coefficients

It is a straightforward procedure to calculate mean annual load estimates for urban runoff constituents on a Kg/Ha basis by assigning appropriate rainfall and runoff coefficient values and selecting EMC mean concentration values from Table 6-24. In and of themselves, however, such estimates seem to be of little utility. Therefore, it was decided to do a comparison of the mean annual loads from urban runoff with those of a "well run" secondary treatment plant. We chose to use TSS = 25 mg/l, BOD = 15 mg/l, and Tot. P = 8 mg/l for the effluents from such plants for the purposes of this order of magnitude comparison. For a meaningful comparison for a specific situation, locally appropriate values should be used. Based upon Table 6-24, the corresponding urban runoff mean concentrations used were TSS = 180 mg/l, BOD = 12 mg/l, and Total P = 0.4 mg/l as typical and TSS = 548 ug/l, BOD = 19 mg/l, and Tot. P = 0.88 mg/l as a "worst case" for comparison purposes.

The value of 0.35 was selected as a typical mean runoff coefficient. It is the median of the NURP mean runoff coefficient database for the twenty projects discussed earlier; their average is 0.42, but we believe that this number is overly weighted by the disproportionate number of highly impervious sites in the database. Assuming an average population density of 10 persons per acre (the average of the NURP sites) and a mean annual rainfall of 40 inches per year, urban runoff averages 104 gallons per day per capita. This is also a reasonable estimate of sewage generation in an urban area. Therefore, as a first cut, the ratio of mean pollutant concentrations of urban runoff and POTW effluents will also be the ratio of their annual loads. Thus, we have;

$$\text{TSS} = \frac{180}{25} \approx 7 \; ; \; \text{BOD} = \frac{12}{15} \approx 0.8 \; ; \; \text{Tot. P} = \frac{0.4}{8} \approx 0.05$$

using typical urban runoff values, and;

$$\text{TSS} = \frac{548}{25} \approx 22 \; ; \; \text{BOD} = \frac{19}{15} \approx 1.3 \; ; \; \text{Tot. P} = \frac{0.88}{8} \approx 0.1$$

using the "worst case" values. These numbers suggest that annual loads from urban runoff are approximately one order of magnitude higher than those from a well run secondary treatment plant for TSS, the same order of magnitude for BOD, and an order of magnitude less for Tot. P.

If the hypothetical urban area just described were to go to advanced waste treatment and achieve an effluent quality of TSS = 10 mg/l, BOD = 5 mg/l, and Total P = 1 mg/l and no urban runoff controls were instituted, the mean annual load reductions to the receiving water would be:

$$\text{TSS} = \frac{25 - 10}{180 + 25} \approx 7\% \; ; \; \text{BOD} = \frac{15 - 5}{12 + 15} \approx 37\% \; ; \; \text{Tot. P} = \frac{8 - 1}{0.4 + 8} \approx 83\%$$

for our typical case, and;

$$\text{TSS} = \frac{25 - 10}{548 + 25} \approx 3\% \; ; \; \text{BOD} = \frac{15 - 5}{19 + 15} \approx 29\% \; ; \; \text{Tot. P} = \frac{8 - 1}{0.88 + 8} \approx 79\%$$

for our "worst case." On the other hand, if urban runoff controls that reduced TSS by 90 percent, BOD by 60 percent, and Total P by 50 percent were instituted, (typical results from a well-designed detention basin), the mean annual load reductions to the receiving water would be:

$$\text{TSS} = \frac{180 - 18}{180 + 25} \approx 79\% \; ; \; \text{BOD} = \frac{12 - 7}{12 + 15} \approx 19\% \; ; \; \text{Total P} = \frac{0.4 - 0.2}{0.4 + 8} \approx 2\%$$

for our typical case, and;

$$\text{TSS} = \frac{548 - 55}{548 + 25} \approx 86\% \; ; \; \text{BOD} = \frac{19 - 8}{19 + 15} \approx 32\% \; ; \; \text{Total P} = \frac{0.88 - 0.44}{0.58 + 8} \approx 5\%$$

Thus, if these pollutants are causing receiving water quality problems, consideration of urban runoff control appears warranted for TSS, both urban runoff control and AWT might be considered for BOD, and only AWT would be effective for Total P.

The foregoing should be viewed as illustrative of a preliminary screening for trade-off studies that can be performed using appropriate values for a specific urban area, rather than as description of any particular real-world case. They are, however, believed useful in providing order of magnitude comparisons. Local values for annual rainfall, runoff coefficient, or point source characteristics that are different than those used in the illustration will of course change the results shown; although in most cases the changes would not be expected to cause a significant change in the general relationship.

As a final perspective on urban runoff loads, Table 6-25 presents an estimate of annual urban runoff loads, expressed as Kg/Ha/year, for comparison with other data summaries of nonpoint source loads which state results in this manner. Load computations are based on site mean pollutant concentrations for the median urban site and on the specified values for annual rainfall and runoff coefficient. Typical values for mean runoff coefficient (based on NURP data) have been assigned for residential land use (Rv = 0.3), commercial land use (Rv = 0.8), and for an aggregate urban area which is assumed to have representative fractions of the total area in residential, commercial, and open uses (Rv = 0.35).

Several useful observations can be made. The annual load estimates which results are comparable to values and ranges reported in the literature. Although the findings presented earlier in this chapter indicated that the land use category does not have a significant influence on site concentrations of pollutants, on a unit area basis total pollutant loads are significantly higher for commercial areas because of the higher degree of imperviousness typical of such areas. For broad urban areas, however, the relatively small fraction of land with this use considerably mitigates such an effect.

Finally, the annual loads shown by Table 6-25 have been computed on the basis of a 40 inch annual rainfall volume. For urban areas in regions with higher

TABLE 6-25. ANNUAL URBAN RUNOFF LOADS KG/HA/YEAR

| Constituent | Site Mean Con. mg/l | Residential | Commercial | All Urban |
|---|---|---|---|---|
| Assumed Rv | | 0.3 | 0.8 | 0.35 |
| TSS | 180 | 550 | 1460 | 640 |
| BOD | 12 | 36 | 98 | 43 |
| COD | 82 | 250 | 666 | 292 |
| Total P | 0.42 | 1.3 | 3.4 | 1.5 |
| Sol. P | 0.15 | 0.5 | 1.2 | 0.5 |
| TKN | 1.90 | 5.8 | 15.4 | 6.6 |
| $NO_{2+3}$-N | 0.86 | 2.6 | 7.0 | 3.6 |
| Tot. Cu | 0.043 | 0.13 | 0.35 | 0.15 |
| Tot. Pb | 0.182 | 0.55 | 1.48 | 0.65 |
| Tot. Zn | 0.202 | 0.62 | 1.64 | 0.72 |

NOTE. Assumes 40 inches/year rainfall as a long-term average.

or lower rainfall, these load estimates must be adjusted. The results presented earlier suggest that pollutant concentrations are not sensitive to runoff volume; however, total loads (the product of concentration and volume) are strongly influenced by the volume of runoff. For estimates using equivalent site conditions (Rv), loads for areas with other rainfall amounts are obtained by factoring by the ratio of local rainfall volume to the 40 inch volume used for the table. Planners who believe that the average annual runoff coefficients in their local areas are substantially different from those used in the table can make similar adjustments.

# CHAPTER 7
# RECEIVING WATER QUALITY EFFECTS OF URBAN RUNOFF

## INTRODUCTION

The effects of urban runoff on receiving water quality are very site specific. They depend on the type, size, and hydrology of the water body, the designated beneficial use and the pollutants which affect that use, the urban runoff (URO) quality characteristics, and the amounts of URO dictated by local rainfall patterns and land use.

A number of the NURP projects examined receiving water impacts in some detail, others less rigorously. Because of the uniqueness of URO water quality impacts, individual project results are considered best used for confirmation and support, rather than as a basis for broad generalizations.

Accordingly, this chapter is structured to address each of the principal categories of receiving water bodies separately; streams and rivers, lakes, estuaries and embayments, and groundwater aquifers. Some can be addressed more thoroughly than others at this time. The approach taken to develop a general, national scale screening assessment of the significance of URO pollutant discharges is to compute anticipated effects using analysis methodologies identified in Chapter 5, where these are appropriate and to compare anticipated effects indicated by such generalizations to specific experiences and conclusions drawn by relevant individual NURP projects.

As with any generalization, there will be exceptions. Specific local situations can be expected which are either more or less favorable than the general case. The results presented herein should therefore be interpreted as representative estimates of a substantial percentage of urban runoff sites, but not all of them.

Receiving waters have distinctive general characteristics which depend on the water body type (e.g., stream, lake, estuary) and relatively unique individual characteristics which depend on geometry and hydrology. Given a minimum acceptable amount of data on water bodies and their setting, it appears possible to make useful generalizations regarding the quantitative effects of urban runoff on concentrations of various pollutants in the receiving waters and to draw inferences concerning the influence urban runoff may have on the beneficial uses of the water bodies. However extending the results of such an analysis to an assessment of the prevalence of urban runoff induced "problems" on a national scale cannot be accomplished in a way would provide an acceptable level of confidence in any conclusions drawn therefrom. In addition to the importance of local hydrology, meteorology, and urban characteristics, the emphasis placed on each of the three elements that influence problem definition;

(1) Denial or serious impairment of beneficial use;

(2) Violation of ambient water quality standards; and

(3) Local perception;

will result in a high degree of site-specificity to the determination of the existence of a problem.

## RIVERS AND STREAMS

### General

Flowing streams carry pollutant discharges downstream with the stream flow. For intermittent stormwater discharges, a specific stream location and the biota associated with it are exposed to a sequence of discrete pulses contaminated by the pollutants which enter with urban runoff. Because of the inherent variability of urban runoff (URO), the average concentrations in such pulses vary, as do their duration and the interval between successive pulses. Table 7-1 summarizes average values for storm duration and intervals between storm events for selected locations in the U.S., based on analysis of long term rainfall records using a methodology (SYNOP) presented in an earlier NURP document (the NURP Data Management Procedures Manual). The information presented provides a sense of the temporal aspects of such intermittent pulses and, by inference, the intermittent exposure patterns to which stream biota are subjected. For many locations, storm pulses are produced for about six hours every three days or more, on average.

A probabalistic methodology has been used to examine the concentration characteristics of the storm pulses produced in streams, given the variability of the relevant processes which are directly involved. Stream flow rates, runoff flow rates, and concentrations vary and result in variable stream concentrations. For streams, it is not the runoff volume per se that is important. The combination of stream and runoff flow rates (together with runoff concentration) determine the pollutant concentration in the stream pulse. The duration of the runoff event and the stream velocity dictate the spatial extent of the storm pulse in the stream. The analysis presented in this section addresses the frequency and magnitude of pollutant concentrations in the instream storm pulses which are produced.

### Runoff and Stream Flow Rates

The local combination of stream and runoff flow rates for an urban location are, as indicated, important determinants of the stream concentrations which will result. For long-range projections, the most appropriate data sources for characterizing these parameters are long-term stream flow gauging records (USGS) and long-term rainfall records (USWS).

Figure 7-1(a) illustrates the regional variation of average daily stream flows expressed as cfs/sq mile of drainage area, based on long-term (50 years or more) gauging records at over 1000 stations. Figure 7-1(b) presents a somewhat simplified regional pattern for average rainfall intensity. The data base for this plot is considerably smaller, consisting of rainfall records (usually 10 to 30 years of record) for approximately 40 cities. Localized peturbations exist, but are smoothed out by contours presented.

TABLE 7-1. AVERAGE STORM AND TIME BETWEEN STORMS FOR SELECTED LOCATIONS IN THE UNITED STATES

| Location | Average Annual Values in Hours | |
|---|---|---|
| | Storm Duration | Time Between Storm Midpoints |
| Atlanta, GA | 8.0 | 94 |
| Birmingham, AL | 7.2 | 85 |
| Boston, MA | 6.1 | 68 |
| Caribou, ME | 5.8 | 55 |
| Champaign-Urbana, IL | 6.1 | 80 |
| Chicago, IL | 5.7 | 72 |
| Columbia, SC | 4.5 | 68 |
| Davenport, IA | 6.6 | 98 |
| Detroit, MI | 4.4 | 57 |
| Gainesville, FL | 7.6 | 106 |
| Greensboro, SC | 5.0 | 70 |
| Kingston, NY | 7.0 | 80 |
| Louisville, KY | 6.7 | 76 |
| Memphis, TN | 6.9 | 89 |
| Mineola, NY | 5.8 | 89 |
| Minneapolis, MN | 6.0 | 87 |
| New Orleans, LA | 6.9 | 89 |
| New York City, NY | 6.7 | 77 |
| Steubenville, OH | 7.0 | 79 |
| Tampa, FL | 3.6 | 93 |
| Toledo, OH | 5.0 | 62 |
| Washington, DC | 5.9 | 80 |
| Zanesville, OH | 6.1 | 77 |
| Mean | 6.1 | 81 |
| Denver, CO | 9.1 | 144 |
| Oakland, CA | 4.3 | 320 |
| Phoenix, AZ | 3.2 | 286 |
| Rapid City, SD | 8.0 | 127 |
| Salt Lake City, UT | 7.8 | 133 |
| Mean | 6.5 | 202 |
| Portland, OR | 15.5 | 83 |
| Seattle, WA | 21.5 | 101 |
| Mean | 18.5 | 92 |

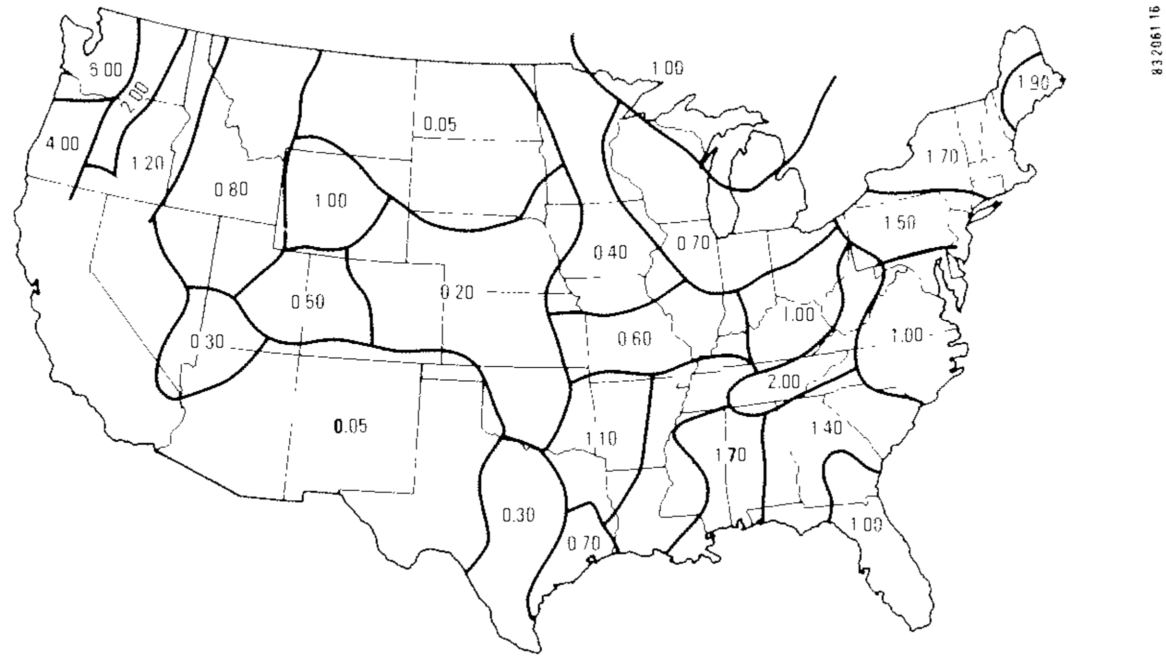



Figure 7-1(a). Regional Value of Average Annual Streamflow (cfs/sq mi)

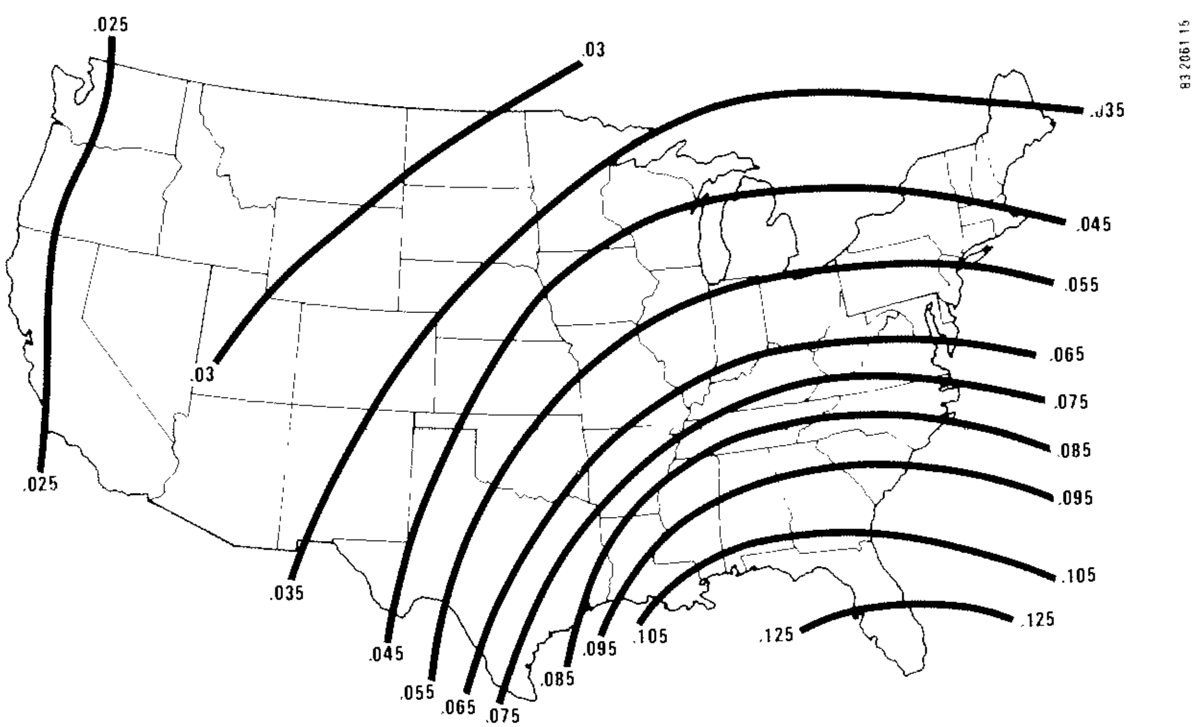



Figure 7-1(b). Regional Value of Average Storm Event Intensity (inch/hr)

Variability of daily stream flows was determined for a smaller sample (about 150 sites) of the stream sites. Variability of storm event average intensities was determined for all of the rain gauge locations in the current data base. These results are summarized in Table 7-2.

### Total Hardness of Receiving Streams

Where the beneficial use of principal concern is the protection of aquatic life, the URO pollutants of major concern appear to be heavy metals, particularly copper, lead and zinc. The potential toxicity of these pollutants are strongly influenced by total hardness, as indicated by Table 5-1 in Chapter 5. Other beneficial uses deal with pollutants and effects that are not influenced by total hardness or (as with drinking water supplies) do not modify the assigned significance of heavy metal concentrations on the basis of total hardness.

As with stream flow and precipitation, distinct regional patterns also exist for receiving water total hardness concentrations. Figure 7-2 delineates the national pattern of regional differences. These patterns impose an additional regional influence on the potential of urban runoff to create problem conditions in streams and rivers.

### Technical Approach To Screening Analysis

The magnitude and frequency of occurrence of intermittent stream concentrations of pollutants of interest, that result from urban runoff, has been computed using the probabilistic methodology discussed in Chapter 5.

The input data required for application of the methodology includes representative values for the mean and variability of stream flow, runoff flow, and runoff pollutant concentrations. The material presented earlier in this chapter provides the basis for assigning values for the flows; the results summarized in Chapter 6 provide the basis for specifying pollutant concentration inputs. In order to translate the probability distribution of stream concentrations (which is the basic output of the analysis methodology) to an average recurrence interval, which is considered to provide a more understandable basis for comparisons, the average number of storms per year is also required. This is estimated directly from the average interval between storm midpoints generated by the statistical analysis of hourly rainfall records.

For a general screening on a national scale, an estimate of typical values for a selected geographic location must be made. This has been done, and the set of input values considered to be typical of geographical location are described and summarized below. The values used should be considered reasonably representative of the majority of sites in the area, but it should be recognized that not all potential sites will have conditions either as favorable or unfavorable as those listed.

We have worked with a limited sample in assigning typical values. A greater data base on rainfall and stream flow would permit greater spatial definition

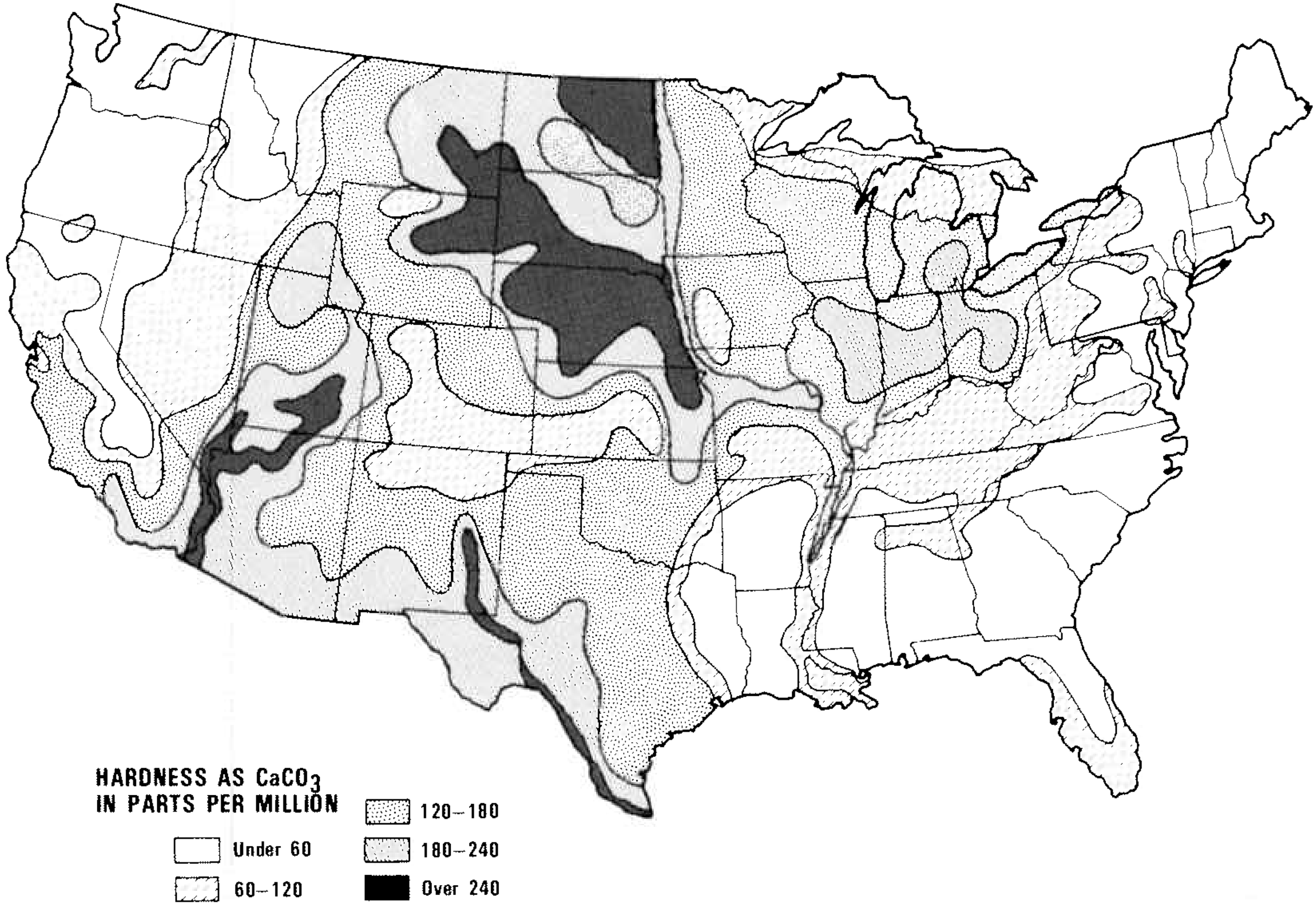



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Figure 7-2. Regional Values for Surface Water Hardness than shown in the results. Specific regions or states could, with development of a more detailed spatial definition of stream flows and rainfall, extend the analysis presented to provide a considerably more comprehensive assessment of problem potential for local areas. This would involve the development of input parameters (rainfall and streamflow) readily derived from available long term USGS stream flow records and USWS rainfall records and their use in the methodology with quality parameters based either on the NURP analysis presented in Chapter 6, or on local monitoring activities.

The analysis methodology presently available permits computation of the probability distribution of instream concentrations, incorporating the effect of upstream (background) concentrations of the pollutant of interest. The results presented here assume upstream concentrations of zero, principally because of our inability at present to make reliable estimates of typical values for the magnitude and variability for pollutants of interest, especially on the broad national scale being examined. As a result, the summaries will show the effects of urban runoff contributions only. In cases where the background is small relative to the URO contribution, the summaries will represent actual conditions quite closely. However, where background is high and has appreciable variability, the implications of the URO contribution will be overstated, particularly the inferred improvement which could result from control of URO.

In order to perform a national screening of regional influences on urban runoff impacts, eight geographical regions illustrated by Figure 7-3 have been delineated. Using the information summarized by Figures 7-1 and 7-2, typical values for the pertinent rainfall/runoff and stream parameters have been assigned for each of the regions. Table 7-2 summarizes the values for these parameters which are used in the screening analysis.

TABLE 7-2. TYPICAL REGIONAL VALUES

| Area | Event Average Rainfall Intensity | | Average Number of Events/year | Average Runoff Flow Rate | | Stream Flow Rate (Daily Avg Flows) | | Stream Total Hardness (mg/l) |
|---|---|---|---|---|---|---|---|---|
| | Mean (in/hr) | c.v. | | Mean Event (cfs/sq mi) | c.v. | Mean (cfs/sq mi) | c.v. | |
| 1 | 0.04 | 1.00 | 110 | 5 | 0.85 | 1.75 | 1.25 | 50 |
| 2 | 0.10 | 1.35 | 100 | 12 | 1.15 | 1.25 | 1.25 | 50 |
| 3 | 0.08 | 1.35 | 90 | 10 | 1.15 | 1.00 | 1.25 | 50 |
| 4 | 0.055 | 1.25 | 110 | 7 | 1.05 | 0.75 | 1.25 | 200 |
| 5 | 0.04 | 1.10 | 63 | 5 | 0.95 | 0.35 | 1.25 | 200 |
| 6 | 0.03 | 1.10 | 70 | 4 | 0.95 | 0.05 | 1.25 | 300 |
| 7 | 0.045 | 1.20 | 30 | 5 | 1.00 | 0.05 | 1.25 | 200 |
| 8 | 0.025 | 0.85 | 80 | 3 | 0.75 | 4.50 | 1.25 | 50 |

Average stream flow and rainfall intensity were taken from the plots, which are based on sources previously described. The estimate for variability of daily stream flows (coefficient of variation) is based on computed values for a sample of about 150 perennial streams. Results for a number of regional

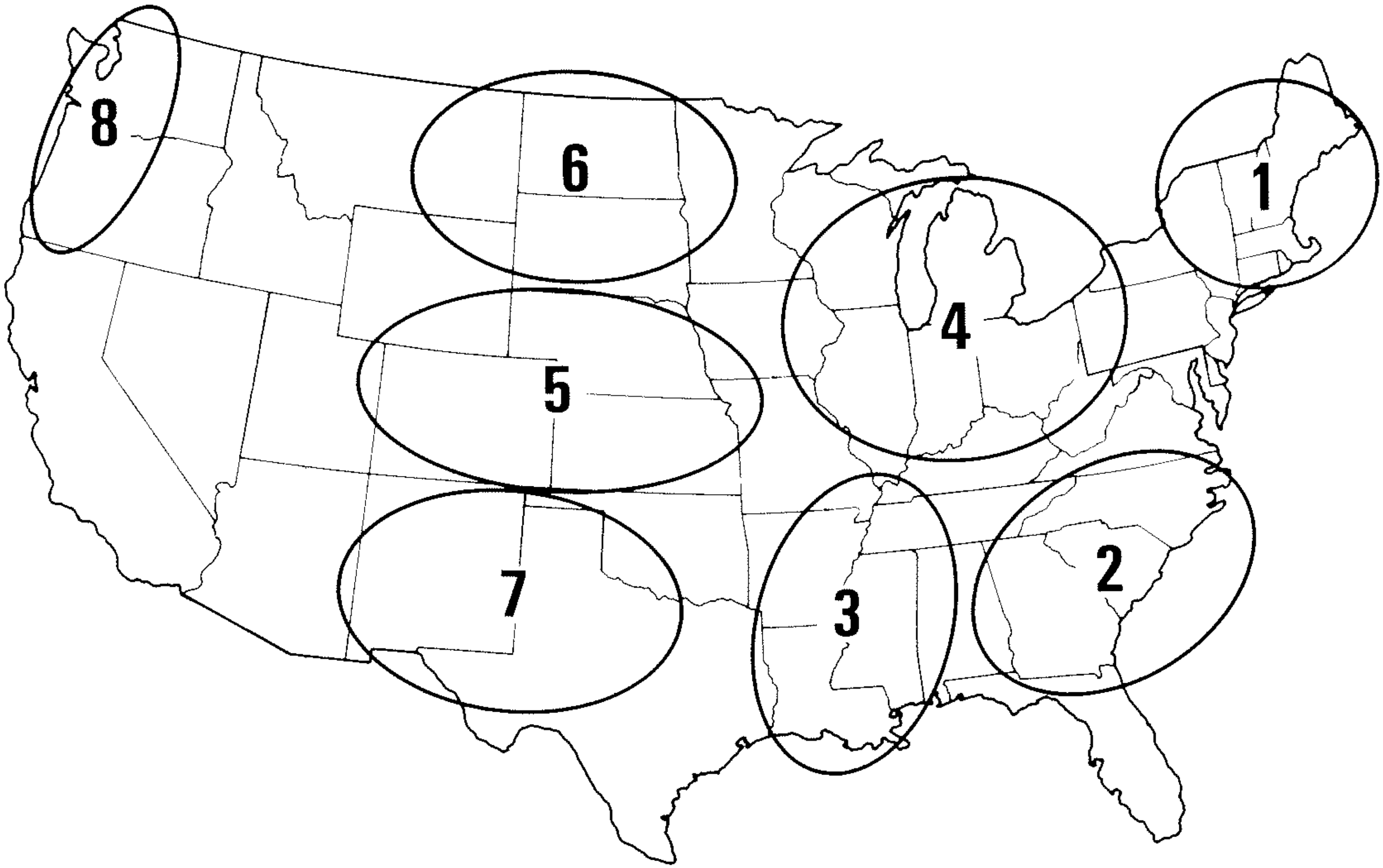


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Figure 7-3. Geographic Regions Selected for Screening Analysis groupings indicated median values for coefficient of variation to fall between approximately 1 and 1.5. Since there were no clear regional patterns apparent, a uniform value for coefficient of variation of stream flows of 1.25 was assigned.

The coefficient of variation of rainfall intensities was taken directly from the statistical analysis of the rainfall records examined. This was reduced by 15 percent to provide estimates of the coefficient of variation of runoff flow rates, based on a recent published report, "Comparison of Basin Performance Modeling Techniques", Goforth, Heaney and Huber, ASCE JEED, November 1983, using the SWMM model on a long-term rainfall record.

The quality characteristics of urban runoff used in the screening analysis are listed in Table 7-3, and are based on the results summarized in Chapter 6. The analysis results have been rounded in the selection of representative site median EMCs and are interpreted as being representative of an array of urban sites discharging into the receiving stream being analyzed.

Average site conditions are based on the 50th percentile of all urban sites. Since the data analysis indicated that sites at some locations tend to cluster at either the higher or lower ends of the range for all sites, high range and low range site conditions were also selected for use in the screening analysis. High range site conditions are nominally based on the 90th percentile of all site median concentrations; the low range on the 10th percentile site. The variability of EMCs from storm to storm at any site is based on the median of the coefficients of variation of EMCs at sites monitored by NURP. This value was used for the low range and average site condition and was increased nominally for the high range site condition.

TABLE 7-3. URBAN RUNOFF QUALITY CHARACTERISTICS
USED IN STREAM IMPACT ANALYSIS
(Concentrations in µg/l)

| | COPPER | | LEAD | | ZINC | |
|---|---|---|---|---|---|---|
| | Site Median EMC | Coef Var | Site Median EMC | Coef Var | Site Median EMC | Coef Var |
| Low Range of Site Conditions | 15 | 0.6 | 50 | 0.75 | 75 | 0.7 |
| Average Site Conditions | 35 | 0.6 | 135 | 0.75 | 165 | 0.7 |
| High Range of Site Conditions | 90 | 0.7 | 350 | 0.85 | 450 | 0.8 |

An illustrative example of a site-specific application of the probabilistic analysis methodology employed is presented in order to:

1. Illustrate the nature of the computational results produced;

2. Assist in the interpretation of the tabulations presented later which summarize results of the national scale screening analysis;

3. Indicate how magnitude/frequency of instream concentrations may be interpreted for inferences concerning the absence or presence of a "problem" and where a problem is concluded to exist, its degree of severity; and

4. Demonstrate how alternative URO control options may be evaluated in terms of their expected impact on water quality and potential effect on problem severity.

From selected representative values for mean and variability of stream and runoff conditions, the probability distribution of resulting instream concentrations during storm events can be computed. Figure 7-4 illustrates a plot of such an output. Uncertainty in estimates for specific inputs can be accommodated by sensitivity analyses which incorporate upper and lower bounds for specific parameter values. Results are then presented as a band rather than a specific projection. The probabilities which are the basic output of the analysis may be converted to average recurrence intervals to provide what is believed to be a more understandable basis for interpreting and evaluating results.

Figure 7-5 presents results converted to the average recurrence interval at which specific stream concentrations will be produced during storm runoff periods.

The significance of a particular magnitude/frequency pattern of stream concentrations caused by urban runoff can be evaluated by comparing them with concentrations which are significant for the beneficial use of the water body. In the example presented, we have excluded comparisons with drinking water criteria on the basis that urban streams are not generally used as domestic water sources, and in any event, the criteria relate to finished water, and surface water supplies almost invariably receive treatment.

Protection of aquatic life is selected for the screening analysis of the impact of urban runoff because it is believed to be the predominant potential beneficial use for urban streams on a national scale. The concentrations which result from urban runoff are compared with stream target concentrations associated with different degrees of adverse impact, as discussed and tabulated in Chapter 5.

In the site specific situation illustrated, the stream concentrations of copper caused by untreated urban runoff discharges exceed the "EPA Maximum" criterion more than ten times per year on average. The concentration level suggested by the NURP analysis to be the Threshold level of adverse biological impacts is exceeded an average of five times per year (recurrence interval 0.2 year), and significant mortality of more sensitive biological species occurs about once every three years on average. Although this stress level may not be great enough to result in a total denial of the use, there are many who would argue that it represents an unacceptably severe degree of impairment of this beneficial use.

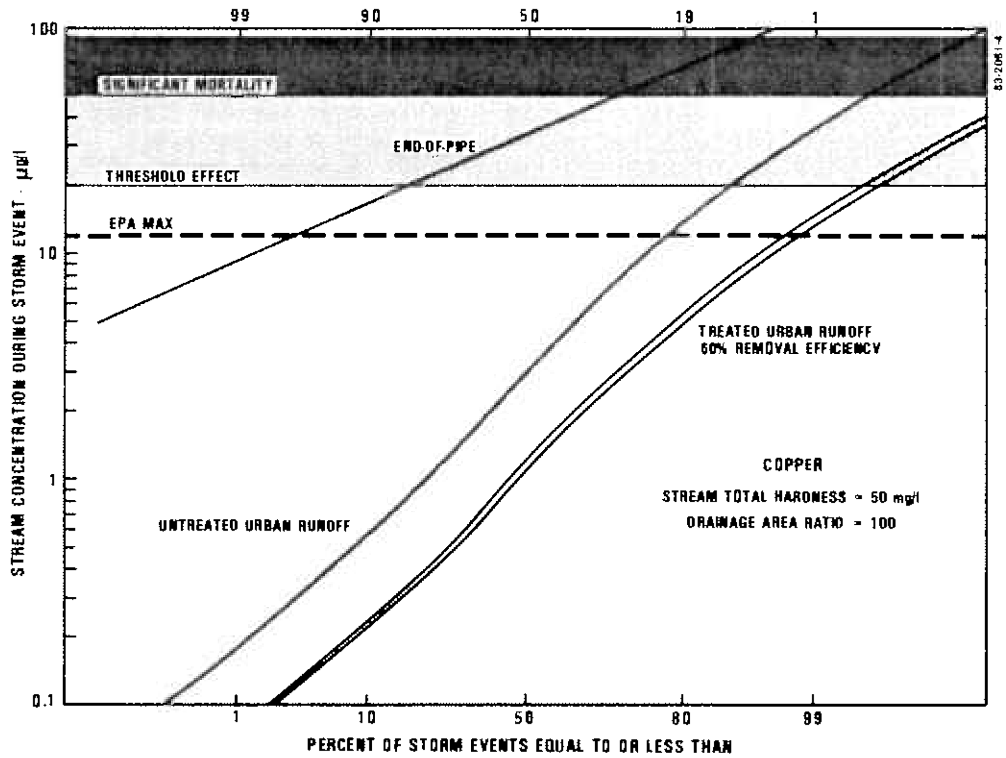



Figure 7-4. Probability Distributions of Pollutant Concentrations During Storm Runoff Periods

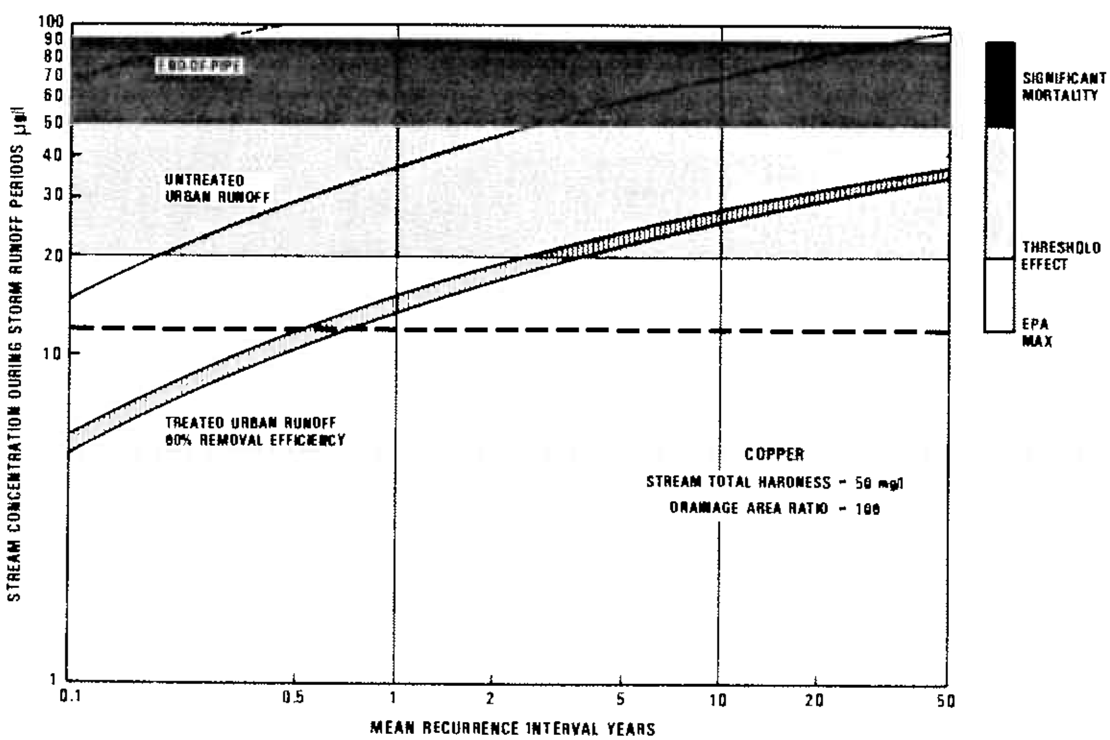



Figure 7-5. Recurrence Intervals for Pollutant Concentrations

The projection labeled "treated urban runoff" may be taken to represent the in-stream result for either the originally considered discharge following the application of controls which effect a 60 percent reduction, or of an uncontrolled urban runoff site with lower levels of copper in the runoff. In this case, threshold levels are reached only once every 3 or 4 years on average, and significant mortality levels are virtually never reached. Even though the ambient "EPA MAX" criterion is exceeded once or twice a year on average, one might conclude that the implied degree of stress is tolerable and is not interpreted to represent a significant degree of impairment of the use.

The Threshold and Significant Mortality levels are estimates, which have been explained earlier. In addition, the "acceptable" frequency at which specific adverse effects can be tolerated is subjective at this time, since there are no formal guidelines. However, an approach of this nature must be taken in any evaluation of the significance of urban runoff and the importance of applying control measures. There are two reasons why this is necessary. First, because of the stochastic nature of the system we are dealing with, virtually any target concentration we elect to specify will be exceeded at some frequency, however rare. Secondly, from a practical point of view, there are limits to the capabilities of controls, however rigorously applied. In the illustration presented, the untreated urban runoff site assigned urban runoff copper concentrations equivalent to the average urban site. Since NURP analysis data indicate that the copper in urban runoff has a soluble fraction of about 40 percent, the level of removal used in the example reflects a control efficiency approaching the practical limit. Receiving water impacts are significantly reduced, but not totally eliminated.

Results of Screening Analysis

A projection of stream water quality responses has been made for each of the eight geographical areas shown by Figure 7-3. The rainfall, runoff, and stream flow estimates used in the computations are those summarized in Table 7-2. The urban runoff quality characteristics used are those presented in Table 7-3.

To consolidate screening analysis results for easier comparison, results are not presented as continuous concentration/frequency curves as used in the illustrative example presented above. Instead, the comparison plots which follow show only the recurrence interval at which specified biological effects levels are exceeded. The concentrations which correspond with these effects are strongly influenced by stream total hardness, and hence vary regionally. Table 7-4, based on information presented in Chapter 5, summarizes the stream target concentrations used in the screening analysis summary.

Analysis results are presented for Copper (Figure 7-6), Lead (Figure 7-7) and Zinc (Figure 7-8). Each individual bar represents a different geographical region, and the analysis is performed for two drainage area ratios. Since regional stream flow differences are based on unit flows (cfs/sq mile of drainage area), actual flow in a receiving stream at a particular location is

TABLE 7-4. REGIONAL DIFFERENCES IN TOXIC CONCENTRATION LEVELS
(Concentrations in μg/l)

| Pollutant | Stream Total Hardness μg/l | Geo-graphic Regions | EPA MAX | Suggested Values For | | |
|---|---|---|---|---|---|---|
| | | | | Threshold Effects[1] | Significant (a) | Mortality[2] (b) |
| Copper | 50 | 1,2,3,8 | 12 | 20 | 50 | 90 |
| | 200 | 4,5,7 | 42 | 80 | 180 | 350 |
| | 300 | 6 | 62 | 115 | 265 | 500 |
| Lead | 50 | 1,2,3,8 | 74 | 150 | 350 | 3200 |
| | 200 | 4,5,7 | 400 | 850 | 1950 | 17,850 |
| | 300 | 6 | 660 | 1400 | 3100 | 29,000 |
| Zinc | 50 | 1,2,3,8 | 180 | 380 | 870 | 3200 |
| | 200 | 4,5,7 | 570 | 1200 | 2750 | 8000 |
| | 300 | 6 | 800 | 1700 | 3850 | 11,000 |

1 Threshold Effects - mortality of the most sensitive individual of the most sensitive species.

2 Significant Mortality

Level (a) - mortality of 50 percent of the most sensitive species.

Level (b) - mortality of the most sensitive individual of 25th percentile sensitive species.

a function of both the unit flow rate and the size of the contributing drainage area. The "drainage area ratio" (DAR) used in the analysis is

$$DAR = \frac{\text{Urban Area Contributing Runoff}}{\text{Stream Drainage Area Upstream of Urban Input}}$$

It is a measure of the location of the urban area relative to the headwaters of the receiving stream.

The shading scheme used on the bars duplicates that used earlier in the illustrative example (Figure 7-5), and identifies the recurrence interval for each of the target concentrations. For example, instream copper concentrations during storm runoff periods in geographic region 1, with average site conditions for copper concentrations in urban runoff, and a DAR = 10, are projected to be as follows (middle plot, Figure 7-6).

- EPA MAX - ambient criterion is exceeded at a frequency of 0.02 year (= 50 times/year) or about every other storm event on average.

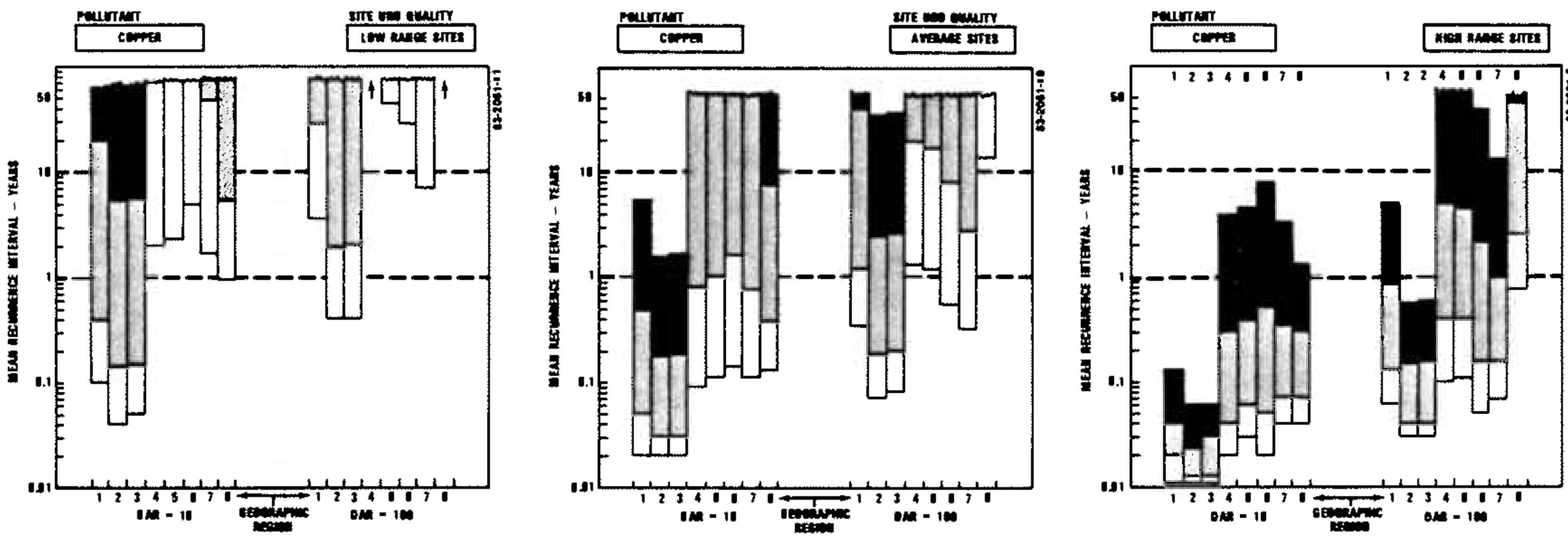



Figure 7-6. Exceedance Frequency for Stream Target Concentration
COPPER

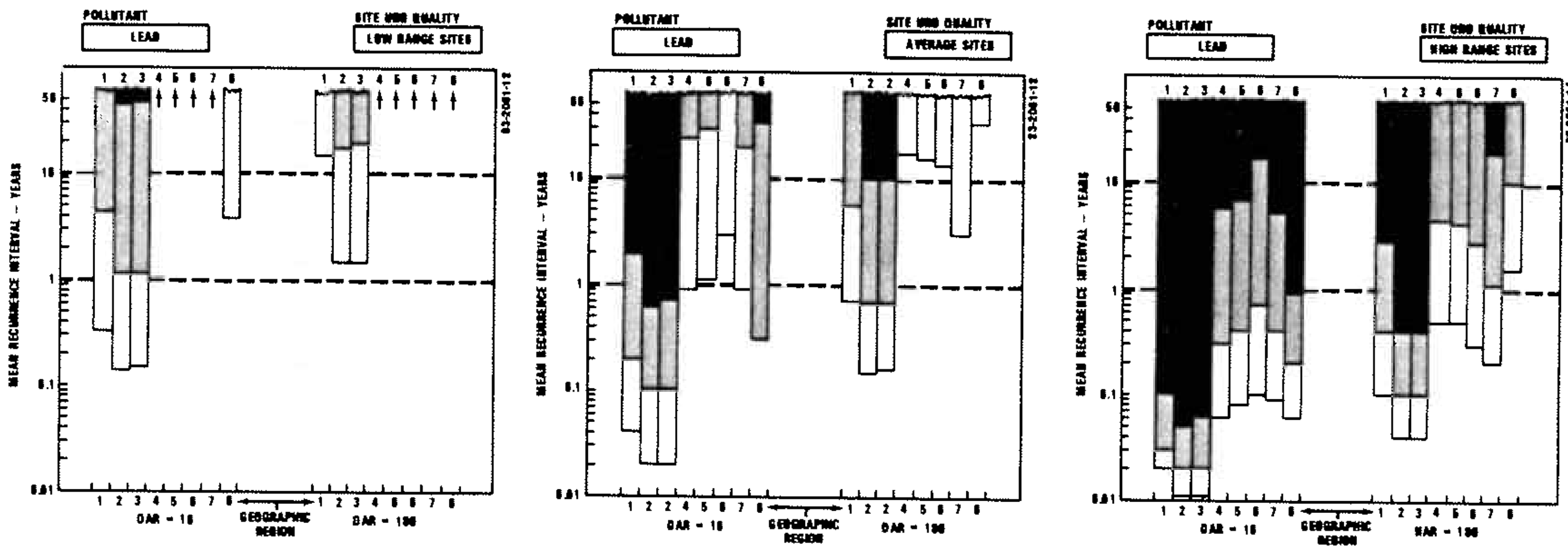



Figure 7-7. Exceedance Frequency for Stream Target Concentration
LEAD

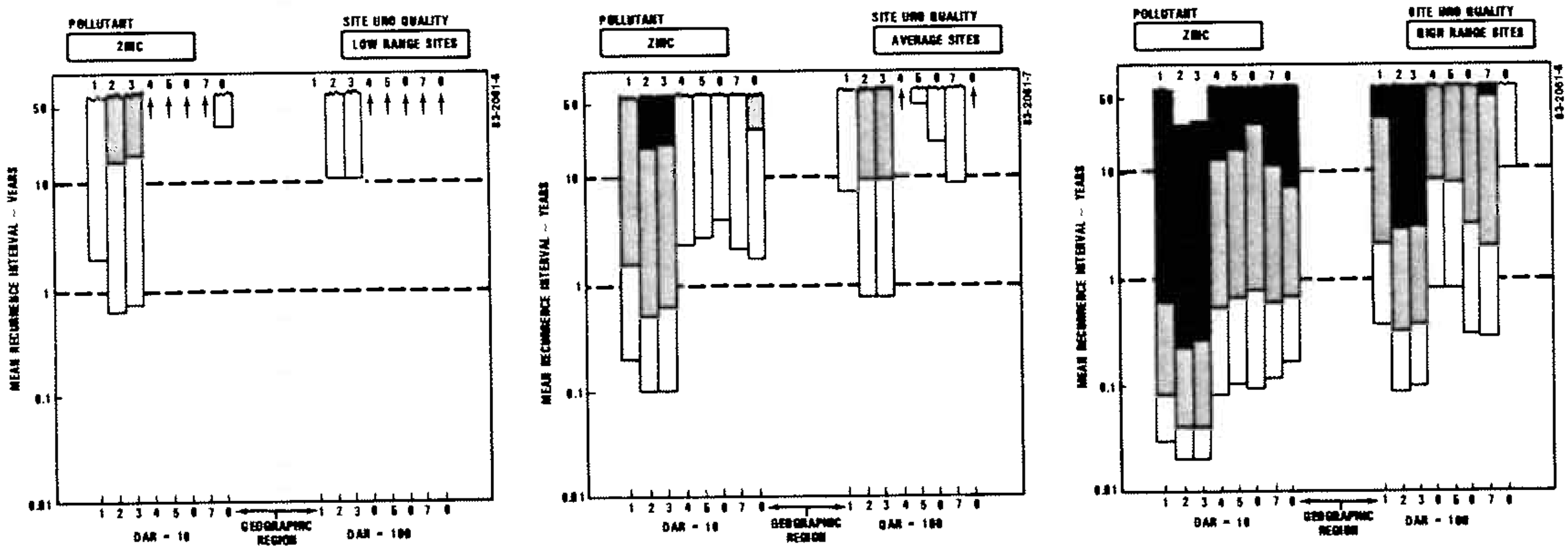



Figure 7-8. Exceedance Frequency for Stream Target Concentration
ZINC

- Threshold concentration levels at which adverse biological stress for short duration exposures is projected to occur have a recurrence interval of about 0.05 years (20 times/year).

- Significant mortality levels are exceeded at intervals of about 0.5 year (twice/year) for the less severe effect, to about once in 5.5 year for the more severe impact specified.

The plot is terminated at an upper level for recurrence interval of 50 years. Although the analysis procedure computes specific recurrence intervals in excess of this value, a realistic interpretation suggests that such conditions are for practical purposes quite unlikely to ever be reached or exceeded. At computed recurrence intervals of about 10 years or more estimates are not considered to be reliable and are very probably conservative. Therefore, indicated mean recurrence intervals in excess of 10 years probably (and 50 years certainly) should be interpreted as "unlikely" or "highly unlikely".

Discussion

An inspection of the screening analysis results (Figures 7-6 through 7-8) indicates the reason why it is unrealistic to attempt a broad generalization on whether urban runoff is, or is not a "problem" in rivers and streams. Water quality impacts can vary widely, depending on regional rainfall and stream hydrology, urban site quality characteristics, drainage area ratio (reflecting the size of the receiving stream relative to the urban area), and the total hardness of the receiving stream. While the screening analysis results provide an informative and useful perspective on the issue, it should be recognized that any specific site may differ considerably from the typical conditions used to characterize rainfall and stream flow for the area, and further, that local variations in runoff quality characteristics within the range defined by the NURP data can also have significant influence. The dominant indication of the analysis is that the problem potential for urban runoff is highly site-specific. Nevertheless some useful generalizations can be made.

Perhaps the major factor which dictates whether urban runoff discharges of copper, lead, or zinc will adversely impact aquatic life is the natural hardness of the receiving streams. As a result, the southeast and gulf coast areas are consistently indicated to be more sensitive than other areas of the country. Of the remaining soft water areas, the northeast is somewhat less sensitive; the Pacific northwest markedly less. This is attributed to significantly lower storm intensities in these areas, coupled in the northwest with appreciably higher stream flows.

Drainage area ratios have an important effect, reflecting as they do the magnitude of stream flow at the urban location. The effect is much greater for geographical regions with high unit flow (cfs/sq mile) than for lower stream flow regions.

Finally, the quality characteristics of the urban sites have a significant influence. Stream concentrations differ markedly depending on whether the local urban sites tend to cluster toward the lower or higher end of the range of site median concentrations indicated by the NURP data base.

A comparison of the relative position of the bars on Figures 7-6, 7-7 and 7-8, is sufficient to indicate the comparative sensitivity to urban runoff pollutant discharges. However, it is also desirable to decide whether a given stream effect constitutes a serious degree of impairment of an aquatic life beneficial use. There are no formal guidelines, and interpretations that are either more liberal or more restrictive than those suggested below may be preferred by others dealing with specific stream segments. For the interpretation of the national scale screening analysis, the following decision basis has been used to identify the situations in which urban runoff is likely to result in a water use "problem", (i.e., cause an unacceptable degree of use impairment):

- Threshold effects - (mortality of the most sensitive individual of the most sensitive species) occur more often than about once a year on average.

- Significant mortality - using the lower of the two levels (i.e., 50 percent mortality of the most sensitive species), occurs more often than about once every 10 years on average.

Using these guidelines for assessing the occurrence of problem situations, copper is shown to be the most significant of the three heavy metals consistently found in urban runoff at elevated concentration levels. Where site concentrations are at the high range of observed urban site conditions, problems are expected in all geographic regions at a DAR = 10, and in all geographic regions except region 8 at DARs as high as 100. When site concentrations are in the average range of observed conditions, problem situations are restricted to geographic regions 2 and 3 (plus region 1 at DAR = 10). When site copper concentrations are in the lower range of observed site conditions, problem situations are restricted to geographic regions 2 and 3 at low DARs. They are marginal (significant mortality once every 5 years) but remain a problem according to the definition adopted. The "marginal" attribution is used here, because the more severe degree of significant mortality (most sensitive individual of 25th percentile sensitive species) is indicated by the analysis virtually never to occur.

Thus, copper discharges in urban runoff are indicated to represent a significant threat to aquatic life use in regions 2 and 3 (southeast and Gulf Coast) under almost all possibilities for urban site runoff quality. In region 1 (northeast), problems would be expected at all but the lower range of site concentrations. In the hard water areas (regions 4, 5, 6, 7) problems are expected only where site runoff quality is in the high end of the range of observed site median concentrations.

It should be noted that the analysis has been based on total copper concentrations in urban runoff. Toxic effects are usually considered to be exerted by the soluble form of the metal, and EPA defines an "active" fraction based on a mild digestion which converts some of the inactive particulates to soluble forms, to account for transformations which may occur in the natural water systems. Copper in urban runoff has a typical soluble fraction of about 50 percent, and the active fraction would therefore fall somewhere between 50 and 100 percent of the total concentration used in the analysis. The analysis has been performed using the total fraction, since adequate information is not available at present to reliably adjust these values. However, although the problem assessment presented above may be somewhat conservative, further refinement along these lines would not change the inferences drawn from the screening analysis results.

Zinc, like copper, has an indicated soluble fraction in the order of 50 percent, and the screening analysis indications will also be unaffected by this consideration. It is indicated to be unlikely to pose a significant threat to aquatic life in most urban runoff situations. Exceptions are restricted to soft water areas in the east and south, lower DARs, and sites with high zinc concentrations in urban runoff.

Lead results must be viewed with greater caution, because soluble fractions in urban runoff are indicated to be quite low (less than 10 percent). Problem indications are therefore likely to be reasonably conservative, i.e., overstate the problem potential. Problem situations may be expected to be restricted to soft water areas in the east and Gulf areas when urban sites have average site concentrations and DARs are low, and even at high DARs when site concentrations are in the high range. Lead is not indicated to be a threat to aquatic life in the hard water areas of the country or in the Pacific northwest, except for the combination of low DAR and high site concentration.

In performing the screening analysis, upstream concentrations were assumed to be zero; that is, the receiving stream had only a diluting effect on the urban runoff pollution. In actual cases background concentrations will be greater than zero, and in some instances upstream contributions (e.g., agricultural runoff, another city) could be significant and result in more severe conditions than those identified in the screening analysis.

On the basis of the foregoing, it appears appropriate to identify copper as the key toxic pollutant in urban runoff, for the following reasons:

- Problem situations anticipated for lead and zinc do not occur under any conditions for which copper does not show up as a problem as well - and with more severe impacts. On the other hand, copper is indicated to be a problem in situations where lead or zinc are not.

- Based on the ratios between concentrations producing increasingly severe effects, copper is suggested to be a more generic toxicant. It has an effect on a broad range of species. This is in contrast to lead and zinc for which a substantially greater degree of species selectivity is indicated. Some species are sensitive, others relatively insensitive to lead and zinc.

- From the NURP data, locations which tend to have site median concentrations in the low, average, or high end of the range have generally consistent patterns for each of the three heavy metals.

- Control measures which produce reductions in copper discharges to receiving waters could be expected to result in equivalent reductions in zinc, and greater reductions in lead, by virtue of its significantly greater particulate fraction.

Copper is accordingly suggested to be an effective indicator for all heavy metals in urban runoff relative to aquatic life. It might be used as the focus for control evaluations, site specific bioassays, monitoring activities, and the like.

It should be noted that while immediate water column impacts of lead are not as significant as those for copper, the high particulate fraction of lead would tend to result in greater accumulations in the stream bed. This aspect has not been addressed by the NURP program in sufficient detail to warrant any comment on its potential significance.

The results of the screening analysis summarized by Figures 7-6 through 7-8 are approximate, because they are influenced by the suitability of the typical values for stream and runoff flows which were assigned. This however can be refined by the use of appropriate values which can be developed from readily available data bases, and thus adjusted for local variations which are to be expected. A second issue relative to the reliability of the projections is the validity of the computations, given that the input parameters are representative. This has been confirmed by a number of validation tests, discussed in the NURP supporting document referenced earlier, which addresses the stream analysis methodology.

The remaining issue for evaluating the reliability of the indications of problem potential produced by the screening analysis is the reasonableness of the intermittent exposure concentration levels, which have been associated with various biological effects levels, and the guidelines adopted for this discussion, which determine whether or not a problem is expected. While rather tenuous at this time, the information available does provide support.

Two of the NURP projects examined aquatic life effects in streams receiving runoff from monitored sites.

- Bellevue, WA concluded that whatever adverse effects were observed were attributable to habitat impacts (stream bed scour and deposition) as opposed to chemical toxicity. For this project, heavy metal concentrations in the monitored urban runoff sites were typical of the average for all urban sites. The screening analysis results under these conditions do not indicate the expectation of a problem.

- Tampa, FL conducted extensive bioassay tests but failed to show any adverse effect of water column concentrations of pollutants in urban runoff. The screening analysis results presented in Figure 7-6 indicate marginal problem conditions at low DAR for this geographic region. At this project however, all monitored sites show heavy metal concentrations significantly lower than the low range conditions used in the screening analysis. When the screening analysis is repeated using site concentrations representative of Tampa monitoring results, a problem situation is not predicted, even at DARs lower than is probably the case for this location.

LAKES

Because lakes provide extended residence times for pollutants, the significant time scale for evaluating urban runoff impacts is at least seasonal, and usually annual or longer, rather than the storm event scale used for streams. The screening methodology identified in Chapter 5, uses annual nutrient loads to assess the tendency for development of undesirable eutrophication effects.

Figure 7-9 illustrates the effect of urban runoff on average lake phosphorus concentration. The very significant influence of area ratio is evident. The larger the urban area which drains into a lake of a given size, the greater the annual loading, and the higher will be the lake phosphorus concentration and the eutrophication effects produced.

The phosphorus concentrations characteristic of the urban sites surrounding a particular lake are also seen to be significant. The three bands shown reflect the range of possibilities, based on the NURP data. The same basis is used to estimate the phosphorus loads from average urban sites and those at the higher and lower ends of site conditions, as was described for heavy metals in the previous section. In this case, because it is annual mass loads which are of interest, site median concentrations have been converted to site mean values for use in the computations.

Lake phosphorus concentrations are also influenced by the annual runoff volume (annual precipitation and runoff coefficient). The results illustrated are based on an annual rainfall of 30 inches and an overall average runoff coefficient of 0.2. Plotted results may be scaled up or down in proportion to the ratio between local values for these parameters and those used in the illustration.

Finally, the lake morphology and hydrology influence the outcome; specifically depth (H) and residence time ($\tau$). This is reflected by the width of each of the bands, which are based on a range of values for $H/\tau$ (1 to 10) estimated to be fairly typical for lakes in urban settings.

If an average lake phosphorus concentration of 20 µg/l is used as a reference concentration to assess the tendency for producing undesirable levels of biostimulation, it is apparent that only lakes with rather small area ratios are likely to be unaffected by urban runoff nutrient discharges. Since the three bands represent different concentration levels of phosphorus in urban runoff, qualitative inferences may be drawn concerning the beneficial use impacts of control activities. More detailed estimates may of course be made by use of the methodology with site specific parameters.

The salient feature of the situation, as generalized by the analysis summarized by Figure 7-9, is that the problem potential of urban runoff for lakes is quite site specific. The illustration considers only urban runoff loads; in an actual situation, all nutrient sources (point and nonpoint)

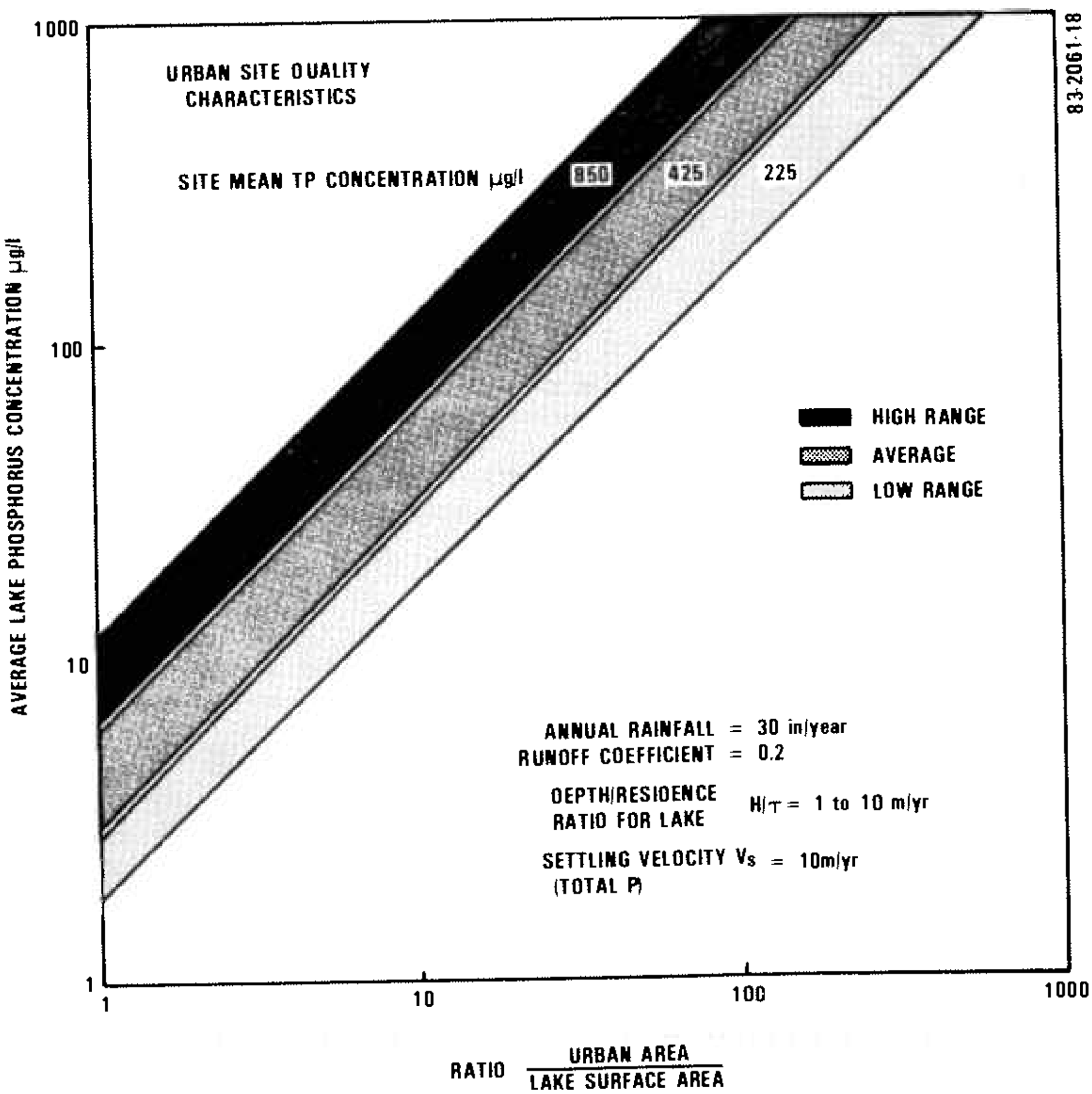



Figure 7-9. Effect of Urban Runoff on Lake Phosphorus Concentrations

would be considered, and this would tend to modify the relative significance of urban runoff on lake conditions.

Several of the NURP projects addressed impacts on lake quality in some depth. These projects include the following:

- Irondequoit Bay, NY - Lake has been highly eutrophic, due to point and nonpoint discharges. Sewage treatment plant and combined sewer overflow discharges have been removed, so that residual sources are recycle from lake sediments and nonpoint sources, including urban runoff, from the contributing drainage area. Further reductions are considered necessary to meet targets. (Area ratio is high at this location.)

- Lake George, NY - Lake is oligotrophic; the study addressed the concern that urban runoff from present and potential future development would unacceptably accelerate degradation of existing water quality. (Area ratio is low at this location.)

- Lake Quinsigamond, MA - Urban runoff was determined to be one of a number of sources preventing water quality objectives from being met. Some control of urban runoff phosphorus loads was recommended as one of the elements of an overall management plan.

Each of the above situations is sufficiently unique, and the mix of urban runoff and other load sources is sufficiently different to suggest that it is inappropriate to attempt a broad generalization. The interested reader may refer to the individual project documents which are available through NTIS for more information.

ESTUARIES AND EMBAYMENTS

These water bodies are normally of sufficient size and complexity that simple screening analyses have not been considered to be sufficiently useful or effective to justify their use.

The Long Island, NY NURP project examined and confirmed that urban runoff sources of coliform bacteria are the principal contributors to the water column concentrations that result in closure of shellfish beds in a number of embayments (principally the Great South Bay). Estimates of control activities that would allow the opening of presently closed areas were also made. The reader is referred to the project documents for further information.

The significance of urban runoff and other nonpoint source loads on eutrophic levels in the Potomac estuary is being investigated under a study which is not associated with the NURP program. However, among other objectives of the WASHCOG NURP project, estimates of urban nonpoint source loads have been developed to support this study.

Although specific situations where urban runoff is significant have been identified, no general assessment for water bodies of this type can be made at this time.

GROUNDWATER AQUIFERS

Much of the precipitation which falls on an area either percolates directly into the ground, or does so after relatively short overland flow distances. This condition is essentially uncontrollable and distinctly different from the case where urban runoff from impervious areas is deliberately collected and routed to a recharge device which causes it to percolate to groundwaters.

This type of control approach is a practical and effective technique for reducing pollutant loads which would otherwise reach surface waters as discussed in Chapter 8. The concern addressed here is with the extent to which groundwater aquifers may be contaminated by this practice.

The Long Island, NY and Fresno, CA NURP projects examined this issue through extensive tests utilizing recharge basins ranging from recent installations to others which have been in service in excess of 20 years. A somewhat simplified consolidation of the salient findings of these two projects is presented below. The interested reader is referred to the individual project report documents, available through NTIS, for the important details and qualifications.

- Most pollutants of importance in urban runoff are intercepted during the process of infiltration and quite effectively prevented from reaching the groundwater aquifers underlying recharge basins. The pollutants tested and found to behave in this manner include the heavy metals, an appreciable number of the organic priority pollutants and pesticides, and coliform bacteria.

- Chlorides, which are sometimes present in urban runoff at elevated concentrations due to road deicing practices, are not attenuated during recharge.

- Pollutants accumulate in the upper soil layers. The concentrations found are a function of the length of time a basin has been in service. Effective retention of pollutants takes place with all soil types tested, ranging from clays to sands. The depth of pollutant penetration is affected by soil type; however in no case did contaminant enrichment of soil exceed several meters depth, and highest concentrations were found near the surface.

- The limit of the ability of the soil to retain the pollutants of interest is unknown. Additional study of this aspect is appropriate. However given the long service periods of a number of the recharge basins studied, this does not appear to represent an imminent concern.

- At both of these NURP locations, groundwater surfaces were at least 20 feet, and often appreciably more, below the base of the recharge device. The indicated findings may not be applicable at locations with shallow depths to groundwater.

- No significant differences in interception/retention of pollutants is apparent for basins with bare versus vegetated recharge surfaces. However vegetation does apparently help to maintain infiltration rates normal for the soil type.

- Surface soil accumulations of priority pollutants in dual purpose installations used for both recharge and recreational use warrants further investigation to determine whether such practice creates unacceptable health risks or requires appropriately designed and conducted maintenance procedures.

CHAPTER 8
URBAN RUNOFF CONTROLS

## INTRODUCTION

This chapter summarizes the information developed by the individual NURP project studies relating to performance characteristics of selected techniques for the control of urban runoff quality. The number of control practices addressed here is considerably smaller than the array of best management practices suggested in prior studies and publications. This is not intended to exclude consideration of other approaches. However, the techniques discussed in this chapter may be taken as an expression of controls considered by the agencies involved to be potentially attractive and practicable at localized planning levels. They represent the practices for which performance data were obtained under the NURP program and which can be analyzed and evaluated in this report.

Most of the NURP projects provide in their project reports a detailed analysis and evaluation of the controls that were studied. These reports are available through NTIS. In addition to this information source, an analysis was performed by EPAs NURP headquarters team, using results available from all project studies. The objective was to provide an overview and a generic description of performance characteristics in a format considered to be useful for planning activities. Thus, in addition to providing a consolidated summary of project results, this chapter presents a summary of the results of applying analysis methodologies developed under the NURP program. Further detail on the former can be obtained by reference to relevant project report documents; a more comprehensive development of the latter is provided in separate NURP documents ("Detention and Recharge Basins for Control of Urban Runoff Quality", and "Street Sweeping for Control or Urban Runoff Quality").

The types of control techniques which received attention (to a greater or lesser degree) in the NURP program can be grouped into four general categories.

- Detention Devices - These include normally dry detention basins typically designed for runoff quantity control, normally wet detention basins, dual purpose basins, over-sized drain pipes, and catchbasins.

- Recharge Devices - These include infiltration pits, trenches, and ponds; open-bottom galleries and catchbasins; and porous pavements.

- Housekeeping Practices - These are principally street sweeping, but also include sidewalk cleaning, litter containers, catchbasin cleaning, etc.

- Other - These include the so-called "living filter" approaches, grassed swales, wetlands, etc.

## DETENTION DEVICES

### General

Detention basins proved to be one of the most popular approaches to urban runoff quality control selected at the local level, based on the number of individual projects which elected to study them and the number of detention devices tested in the study. It is perhaps instructive to note that nearly all the detention facilities studied were either already in place, or required only modifications of outlet structures before initiation of the NURP-supported studies. In general, detention devices proved to provide a highly effective approach to control of urban runoff quality, although the design concept has a significant bearing on performance characteristics.

Table 8-1 lists the NURP projects that included detention devices as elements of their study program. Both the number of devices, and the number of storms analyzed vary considerably, as indicated in Table 8-1, depending on project priorities and other relevant activities. As a result, not all of the sites are incorporated in the summary presented below. The Washington Area Council of Governments (WASHCOG) conducted a particularly thorough and comprehensive investigation of control techniques, particularly detention basins. They have prepared several useful and informative analyses of performance results on these devices.

### Dry Basins

This is a type of detention basin which is currently in fairly extensive service in various parts of the country. The performance objective of such basins is commonly called "peak shaving", that is, to limit the maximum rate of runoff to some preselected magnitude, usually a maximum pre-development rate. The purpose is to control flooding and erosion potential in areas downstream of new development. Such basins employ a bottom outlet having a hydraulic capacity restricted to the maximum allowable flow. Runoff from smaller storms flows along the bottom of the basin and is discharged without restriction. Flows in excess of design are backed up in the basin temporarily and ponding occurs only during larger storms and for relatively short periods of time. This class of retention basin is thus normally dry.

Performance of such basins, from a pollutant removal aspect, range from insignificant to quite poor. Accordingly, the limited data available are not discussed in this chapter.

### Wet Basins

This designation covers detention basins which maintain a permanent pool of water. They may vary considerably in appearance, ranging from natural ponds or small lakes dedicated urban runoff control to enlarged sections in

TABLE 8-1. DETENTION BASINS MONITORED BY NURP STUDIES

| Project | Site | Design Type | No. Events in/out |
|---|---|---|---|
| CO1 Denver | North Ave | Dry Basin | 39/21 |
| DC1 Washington, D.C. | Burke | Wet Basin | 60/35 |
| | Lakeridge | Dry Basin | 49/41 |
| | Stedwick | Dual-Purpose | 48/34 |
| | Westleigh | Wet Basin | 41/45 |
| IL2 N. Illinois | Lake Ellyn | Wet Basin | 29/23 |
| MI1 Lansing | Dryer Farms | Dry Basin | 2/8 |
| | Grace St. N* | Wet Basin | 23/21 |
| | Grace St. S* | Wet Basin | 20/22 |
| | Waverly Hills | Wet Basin | 35/30 |
| MI3 Ann Arbor | Pitt-AA | Wet Basin | 6/6 |
| | Traver | Wet Basin | 5/5 |
| | Swift Run | Wet Basin | 5/5 |
| NY1 Long Island | Unqua Pond | Wet Basin | 8/8 |

* These are oversized storm drains installed below street level. Inverts of control sections are below the general grade line, so a permanent pool is maintained.

constructed drainage systems. Runoff from an individual storm displaces all or part of the prior volume, and the residual is retained until the next storm event. This pattern may or may not be modified by natural base inflows during dry weather depending on the local situation.

Detention basins utilizing this design concept have been shown by the NURP studies to be capable of highly effective performance in urban runoff applications, as summarized below. Although performance characteristics of individual basins ranged from poor to excellent, analysis shows these differences to be attributable to the size of the basin relative to the connected urban area and local storm characteristics. Performance data also indicate that in addition to removal of particulate forms or pollutants by sedimentation, some basins exhibit substantial reductions in soluble nutrients (soluble phosphorus, nitrate + nitrite nitrogen). This is attributed to biological processes which are permitted to proceed in the permanent water pool.

There are a number of ways to characterize detention basin performance. The primary basis selected by NURP for doing so is to define performance efficiency on the basis of the total pollutant mass removed over all storms. This provides a meaningful general measure for comparison, is relevant for water quality effects associated with extended time scales (e.g., nutrient load impacts on lakes), and conforms with the capabilities of the NURP analysis methodology developed to provide a planning-level basis for estimating cost/benefit differences in size or application density of this type control.

Table 8-2 tabulates performance in terms of reduction in pollutant mass loads over all monitored storm events. The analysis methodology developed under the NURP program activities suggests that performance should be expected to improve as the overflow rate (QR/A = mean runoff rate ÷ basin surface area) decreases and as the volume ratio (VB/VR = basin volume ÷ mean runoff volume) increases. The NURP basins used in the analysis are listed in increasing order of expected performance capabilities.

The wide range of relative basin sizes provided by this data base is apparent, and performance is seen to generally correspond with expectations. The poorest performance occurs in a basin with an average overflow rate during the mean storm of about six times the median settling velocity (1.5 ft/hr) of particles in urban runoff. In addition, less than 5 percent of the mean storm runoff volume remains in this basin following the event, to be susceptible to additional removal by quiescent settling during the interval between storms. The basins which exhibit high removal efficiencies, at the other end of the scale, have size relationships which result in the mean storm displacing only about 10 percent of the available volume, and producing overflow rates which are only a small fraction of the median particle settling velocity.

This rationale is described more completely in the supporting NURP document on detention basins identified earlier. The testing of the methodology against the NURP monitoring data is presented, and the basis for the performance projections illustrated below is documented.

Figure 8-1 presents a projection of removal efficiency of urban runoff detention devices as a function of basin size relative to the contributing catchment area and regional differences in typical rainfall patterns. The removal rates apply for TSS, which are all settleable, and must be factored by the particulate/soluble fraction of other pollutants which have significant soluble fractions in urban runoff. It applies for the specific basin average depth and area runoff coefficient indicated (which are fairly typical based on NURP data). However performance relationships could be different than indicated based on relevant local values for the controlling parameters.

An alternate approach for characterizing performance of detention basins concentrates on the variable characteristics of individual storm events and how these are modified by the detention device. A comparison of the mean and coefficient of variation of basin inflow and discharge concentrations provides another measure of performance of an urban runoff detention device.

TABLE 8-2. OBSERVED PERFORMANCE OF WET DETENTION BASINS
REDUCTION IN PERCENT OVERALL MASS LOAD

| Project and Site | No. of Storms | Size Ratios | | Average Mass Removals - All Monitored Storms (Percent) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | QR/A | VB/VR | TSS | BOD | COD | TP | Sol.P | TKN | $NO_{2+3}$ | T.Cu | T.Pb | T.Zn |
| Lansing Grace St. N. | 18 | 8.75 | 0.05 | (-) | 14 | (-) | (-) | (-) | (-) | (-) | (-) | 9 | (-) |
| Lansing Grace St. S. | 18 | 2.37 | 0.17 | 32 | 3 | (-) | 12 | 23 | 7 | 1 | (-) | 26 | (-) |
| Ann Arbor Pitt-AA | 6 | 1.86 | 0.52 | 32 | 21 | 23 | 18 | (-) | 14 | 7 | • | 62 | 13 |
| Ann Arbor Traver | 5 | 0.30 | 1.16 | 5 | (-) | 15 | 34 | 56 | 20 | 27 | • | • | 5 |
| Ann Arbor Swift Run | 5 | 0.20 | 1.02 | 85 | 4 | 2 | 3 | 29 | 19 | 80 | • | 82 | (-) |
| Long Island Unqua | 8 | 0.08 | 3.07 | 60 | (TOC=7) | | 45 | • | (-) | (-) | • | 80 | • |
| Washington, D.C. Westleigh | 32 | 0.05 | 5.31 | 81 | • | 35 | 54 | 71 | 27 | • | • | • | 26 |
| Lansing Waverly Hills | 29 | 0.04 | 7.57 | 91 | 69 | 69 | 79 | 70 | 60 | 66 | 57 | 95 | 71 |
| NIPC Lake Ellyn | 23 | 0.10 | 10.70 | 84 | • | • | 34 | • | • | • | 71 | 78 | 71 |

Notes: (-) Indicates apparent negative removals.

• Indicates pollutant was not monitored.

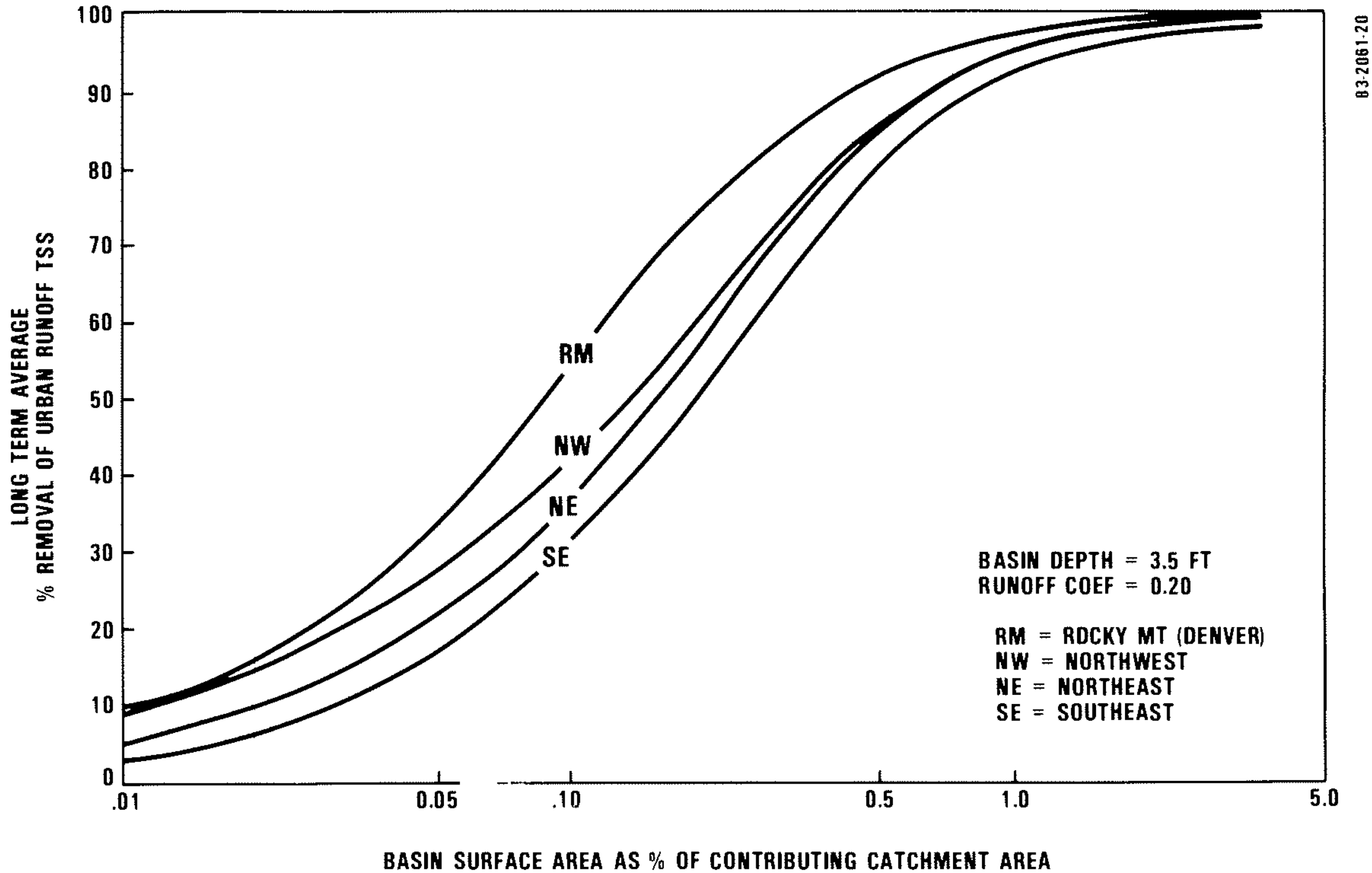



Figure 8-1. Regional Differences in Detention Basin Performance

This approach provides more useful information for subsequently evaluating the effect of controls on water quality impacts on rivers and streams. As evident from the discussion in Chapter 6, reductions in the mean and variability of runoff concentrations (and the inferred reduction in mean and variability of runoff rates) will have a significant beneficial effect on the severity of impacts on flowing streams.

Table 8-3 summarizes detention basin performance when assessed in this manner. It should be noted that in most cases more inlet storm events were monitored than discharge events, and that some inlet events do not have a matching discharge event and vice-versa. Further, for the larger basins where storm inflow displaces only a fraction of the basin volume, it is unlikely that influent and effluent for a specific event represent the same volume of water. The tacit assumption in this analysis is that the inflow events which were monitored provide a representative sample of the total population of all influent event mean concentrations (EMCs). Similarly, the monitored effluent events are assumed to be a representative sample of all basin discharge EMCs. The appropriateness of this assumption is obviously more uncertain where the number of individual storm events monitored is small.

For each basin influent and effluent, the arithmetic mean and variance were computed based on the relationships for lognormal distributions. The percent reduction in the mean concentration and the coefficient of variation are tabulated (Table 8-3). Note that where the number of monitored events shown in this table differ from those listed in Table 8-2, it is because the mass removal computations were restricted to synoptic storms (i.e., matching influent and effluent results were available for an event).

Performance characteristics are generally consistent using either approach, even though each displays a different type of information. Performance improves with detention basin size relative to catchment size and hence the magnitude of the runoff processed. Giving greater weight to the sites monitoring large numbers of storms, indications are that for most pollutants wet ponds also generally result in a considerable reduction in the variability of pollutant concentrations.

A significant exception to this tendency to reduce variability is shown for the soluble nitrogen forms ($NO_2$ + $NO_3$). The positive removal efficiency indicated by reduction of mean concentrations must be attributed to biological processes rather than sedimentation. A substantial increase in variability is consistently indicated by the data. Among the heavy metals, lead which is nearly all in particulate form shows significant reductions in variability. Copper and zinc which have high (40 to 60 percent) soluble fractions show an ambiguous pattern with regard to changes in variability.

In a few of the cases where atypical results are indicated, unique local conditions suggest plausible explanations. For example, at the Ann Arbor (Traver) site, erosion from an unstabilized bank at the outlet of this newly constructed basin is attributed to the poor suspended solids removal observed. The poor removal characteristics at the Unqua site for TKN and nitrate may be associated with the significant wildfowl population at this site.

TABLE 8-3. OBSERVED PERFORMANCE OF WET DETENTION BASINS
(PERCENT REDUCTION IN POLLUTANT CONCENTRATIONS)

(a) Mean EMC

| Project and Site | No. of Storms (1) | Percent Reduction in Mean EMC | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TSS | BOD | COD | TP | Sol.P | TKN | $NO_{2+3}$ | T.Cu | T.Pb | T.Zn |
| Lansing Grace St. N. | 23/20 | (6) | (26) | 15 | (10) | (26) | 11 | (1) | (9) | 39 | (9) |
| Lansing Grace St. S. | 18/17 | 22 | 4 | (3) | 6 | 0 | (5) | (20) | 25 | 14 | 7 |
| Ann Arbor Pitt-AA | 6/6 | 38 | 17 | 23 | 28 | (2) | 11 | 8 | · | 59 | 22 |
| Ann Arbor Traver | 5/5 | 0 | (66) | 12 | 37 | 63 | 19 | 28 | · | · | 19 |
| Ann Arbor Swift Run | 5/5 | 83 | 11 | (3) | (38) | 21 | 25 | 77 | · | 86 | · |
| Long Island Unqua | 8/8 | 34 | (TOC=26) | | 38 | · | (31) | (10) | · | 78 | · |
| Washington, D.C. Westleigh | 40/40 | 83 | · | 33 | 59 | 70 | 19 | 28 | 10 | · | 10 |
| Lansing Waverly Hills | 35/30 | 87 | 52 | 52 | 69 | 56 | 30 | 54 | 53 | 93 | 58 |
| NIPC Lake Ellyn | 25/20 | 92 | · | 64 | 61 | 62 | · | 82 | 88 | 91 | 87 |

(b) Coefficient of Variation of EMCs

| Project and Site | No. of Storms (1) | Percent Reduction in Coef of Variation of EMCs | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TSS | BOD | COD | TP | Sol.P | TKN | $NO_{2+3}$ | T.Cu | T.Pb | T.Zn |
| Lansing Grace St. N. | 23/20 | 14 | 49 | 35 | (7) | (13) | 30 | 0 | 0 | 45 | (31) |
| Lansing Grace St. S. | 18/17 | (7) | (59) | 39 | 13 | 0 | 20 | 21 | 17 | 18 | 15 |
| Ann Arbor Pitt-AA | 6/6 | 17 | (6) | 10 | 28 | (84) | 37 | 0 | · | 53 | (5) |
| Ann Arbor Traver | 5/5 | 14 | (109) | 58 | (3) | 42 | (150) | (82) | · | · | 0 |
| Ann Arbor Swift Run | 5/5 | (5) | 39 | 50 | (150) | 0 | 20 | (150) | · | 26 | · |
| Long Island Unqua | 8/8 | (87) | (TOC=66) | | 47 | · | 19 | (66) | · | 65 | · |
| Washington, D.C. Westleigh | 40/40 | 46 | · | (26) | 15 | 20 | 41 | (280) | 0 | · | (14) |
| Lansing Waverly Hills | 35/30 | 38 | 5 | 69 | 34 | 26 | (8) | (198) | (22) | 34 | (36) |
| NIPC Lake Ellyn | 25/20 | 44 | · | 41 | 71 | 48 | · | (115) | 60 | 19 | 41 |

Notes: (1) In/Out; numbers are approximate, and vary with pollutant. Removals in parentheses indicate negative removal.

Dot (·) indicates pollutant either not monitored or number of observations is too small for reliable estimate of percent reduction.

The ability of detention basins to reduce coliform bacteria concentrations is also of considerable interest because of the significant impact these urban runoff contaminants exert on recreational or shellfish harvesting beneficial uses. Other than at the Unqua site of the Long Island NURP project, the number of observations made for indicator bacteria were too few to support a reliable assessment of the ability of detention basins to effect quality improvements. However, extensive data of this nature were secured on detention basin influent and effluent during all monitored storms at the Unqua site.

Since coliform bacteria have a high rate of die-off in natural waters, performance characteristics based on total mass reductions are not particularly meaningful. The Unqua site data were analyzed to evaluate performance in terms of reductions in concentration levels. Over eight monitored storms at this site, covering a wide range in storm size, the mean EMC (MPN/100 ml) was reduced by 94 percent for total coliform, 91 percent for fecal coliform, and 95 percent for fecal streptococcus bacteria. Variability of bacteria concentrations in the pond outlet increased, with effluent coefficients of variation ranging from about 10 to 100 percent greater than influents. Accordingly, detention basins employing permanent pools (wet ponds) are indicated to be capable of substantial reductions in indicator bacteria.

Dual Purpose Basins

In the absence of a well defined terminology, we have adopted this designation to define basins that are normally dry, and hence retain their full potential for flood control, but which have outlet designs that result in a slow release rate for detained storm flows. Detention time is extended considerably compared with that provided by dry basins employing conventional outlet designs.

One of the detention basins examined by the WASHCOG NURP project, was of this type. This project designates such designs as "Extended Detention Dry Ponds." The pond was converted from a conventional dry pond by replacing the outlet pipe with a perforated riser enclosed in a gravel jacket. The modification was designed to detain stormwater runoff for up to 24 hours, instead of the 1 to 2 hours typically observed in conventional dry ponds.

For undetermined reasons, average detention periods during the study were in the order of 4 to 8 hours, and hence considerably shorter than the design objective. Nevertheless, based on monitoring of more than 30 storm events, the removal of particulate forms of urban pollutants was typically high and comparable to the performance efficiency of wet ponds.

Observed removals for this site (Stedwick) are summarized by Table 8-4, showing percent reductions in both mass and concentration distributions. The principal differences in performance of dual purpose basins compared with wet basins are suggested by the available data to consist of the following:

- Soluble pollutants (e.g., soluble P and Nitrate/Nitrite) are not effectively reduced because of the absence of a permanent pool within which biological reactions have an opportunity to occur in addition to sedimentation.

- The variability of pollutant EMC's does not appear to be modified to the extent that this occurs in wet ponds.

TABLE 8-4. PERFORMANCE CHARACTERISTICS OF A DUAL-PURPOSE DETENTION DEVICE

(Stedwick Site - Washington Area NURP Project)

| Pollutant | Percent Reduction In | | |
|---|---|---|---|
| | Pollutant Mass Load Over All Monitored Storms | Pollutant EMC's | |
| | | Mean | Coef Var |
| TSS | 64 | 63 | (31) |
| COD | 30 | 41 | 17 |
| Total P | < 15 | 11 | 0 |
| Sol P | 1 | (4) | (13) |
| TKN | • | 8 | (11) |
| Organic N | 30 | • | • |
| $NO_{2+3}$ | 10 | 13 | 6 |
| T. Cu | • | • | • |
| T. Pb | 84 | • | • |
| T. Zn | 57 | 43 | 33 |

Although the performance characteristics of basins of this type are indicated to be somewhat inferior to the potential offered by wet ponds, there are a number of considerations which make dual purpose basins highly attractive candidates for quality control of urban runoff. These include the fact that flood control requirements are likely to be more economically obtained than with wet basins and that many existing stormwater management basins may be readily modified to significantly enhance their capability for improving the quality of urban runoff. In areas where ordinances requiring conventional stormwater management ponds are already in existence, the only changes required would be an alternate specification of the outlet design.

Costs

The information presented here is intended to provide an order of magnitude estimate of the cost of providing different levels of control of urban runoff pollutant discharges, when wet detention devices are used as the best management practice (BMP). The summary is based on the size versus performance relationship presented earlier in Figure 8-1 and on the size versus cost relationships presented below.

The analysis is based on cost information developed by the WASHCOG NURP project and discussed in detail in one of their project reports produced for the NURP effort. Construction cost estimates as a function of basin volume are shown by Figure 8-2, adopted from this source. This estimate compares quite favorably with a similar cost/size relationship developed previously by the Soil Conservation Service (SCS).

The cost relationship shown by this figure applies to "dry pond" designs and relates only to expected cost of construction activities. For specific cost estimates, the results derived from Figure 8-2 should be modified as appropriate, in accordance with the following:

- The highly variable capital cost of land acquisition is not included in the construction costs.

- Outlet modifications to provide a dual purpose basin design will increase construction costs by about 10 to 12 percent.

- Pond designs which meet the peak shaving requirements of conventional (dry) pond designs, but also provide a permanent pool of water may have costs up to 40 percent greater than indicated by the cost relationship shown by Figure 8-2.

- An additional allowance equal to 25 percent of construction costs is suggested to allow for planning, design, administration, and construction related contingencies.

- Operation and maintenance costs are estimated to involve an annual expenditure of approximately 3 to 5 percent of base construction cost, that is, before application of the 25 percent factor for design, planning, and administration. The total is composed of two elements: 2 to 3 percent of construction cost estimates the annual cost of routine maintenance and upkeep; an additional 1 to 2 percent of construction cost estimates the annualized cost of sediment removal operations for a 10 year clean-out cycle.

Planning agencies often distinquish between "on-site" controls, which are applied to relatively small urban catchments, often installed by the developer of an urban property, and "off-site" controls, which involve larger basins and serve substantially larger urban drainage areas. Because of the appreciable economy of scale inherent in the cost relationship defined by Figure 8-2, this factor must be taken into account in developing cost/performance summaries for urban runoff quality control using detention basins. Accordingly, the control costs presented below for wet basin designs indicate the differences based on the size of the urban catchment the basin is designed to serve.

Figure 8-3 presents a planning level approximation of both present value and annual cost of wet detention basins. Amoritization of costs is based on a 20 year basin life and an interest rate of 10 percent.

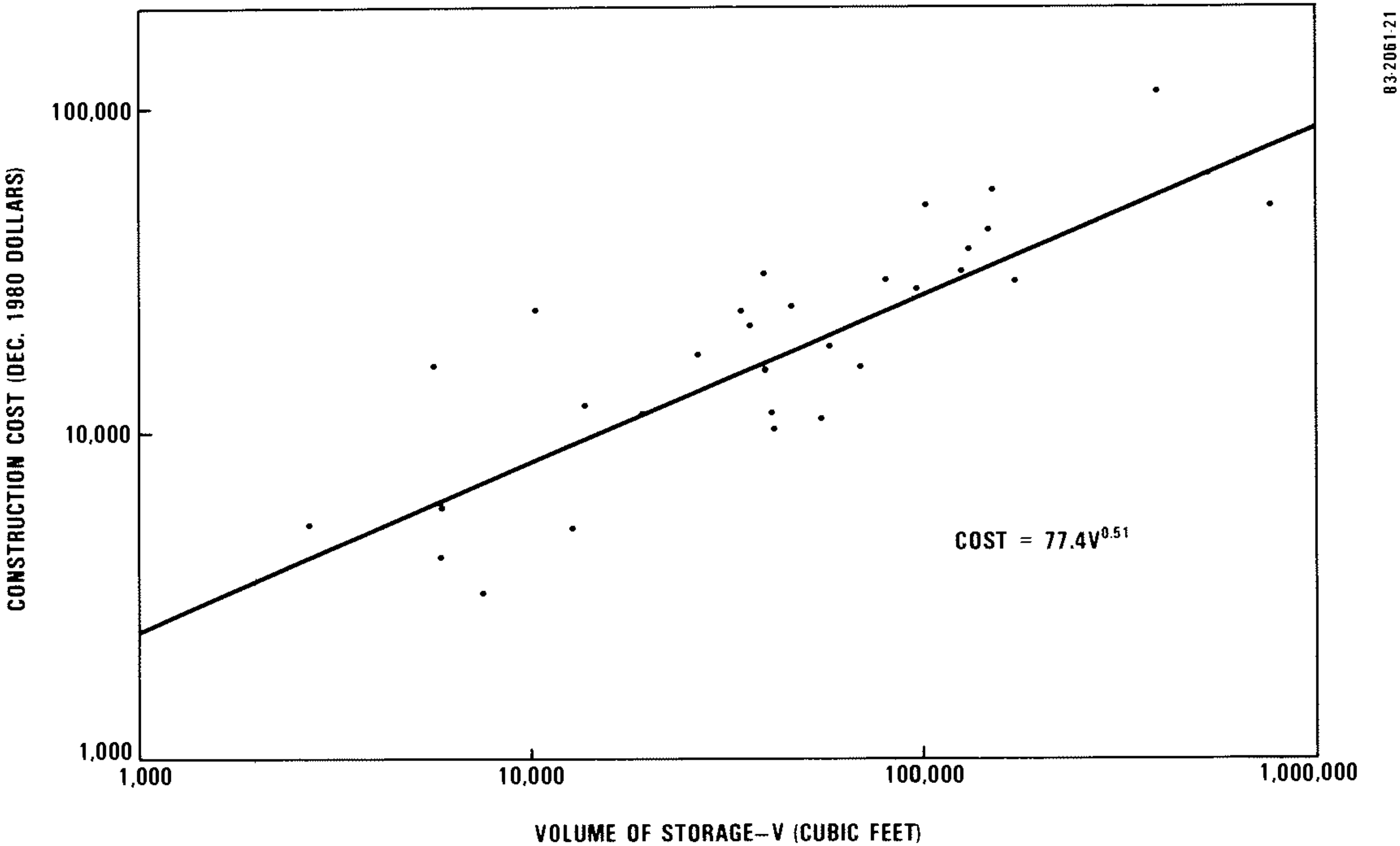
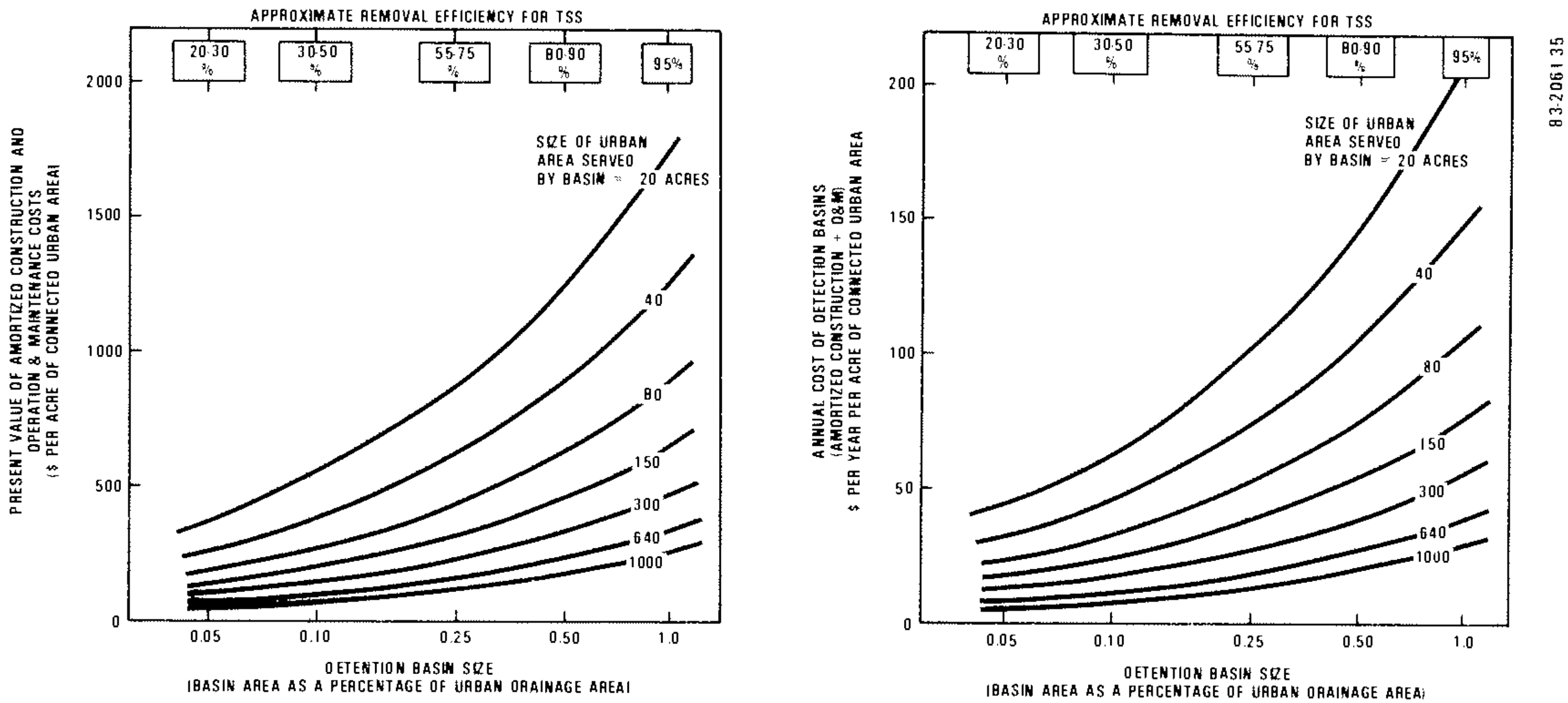



Figure 8-2. Average Stormwater Management (Dry) Pond Construction Cost Estimates Vs. Volume of Storage




BASIS WET BASINS--CONSTRUCTION COSTS 40% GREATER THAN FIGURE 8-2
ANNUAL O&M COST--5% OF BASE CONSTRUCTION COST
BASIN AVG DEPTH 3.5 FEET
INTEREST RATE 10%
BASIN LIFE 20 YEARS

Figure 8-3. Cost of Urban Runoff Control Using Wet Detention Basins

The performance levels associated with a particular basin size are shown at the top of the plots as a range for long-term average removal efficiencies for TSS. The range associated with a particular size reflects the regional differences in performance which can be expected (Figure 8-1) as a result of regional differences in storm characteristics. Approximate removal efficiencies for pollutants other than TSS can be estimated by factoring the indicated TSS removal by the particulate fraction of the pollutant of interest. The supplementary NURP document dealing with detention basins provides information to permit further refinement. A more concise local summary of cost/performance relationships can be developed using the NURP data and analysis methods, if local rainfall and land use characteristics, and design and planning preferences are utilized.

The generalized relationships shown by Figure 8-3 can be summarized as follows, if an urban catchment size of 20 to 40 acres is taken to represent a typical "on-site" control application, and an "off-site" application is reflected by detention basins serving 640 to 1000 acres.

| Control Application | Approximate Level of Control (% TSS Reduction) | Cost Per Acre of Urban Area (Approximate) | |
|---|---|---|---|
| | | Present Value | Annual Cost |
| On-site | 50 | \$500 - \$700 | \$60 - \$80 |
| | 90 | \$1000 - \$1500 | \$125 - \$175 |
| Off-site | 50 | \$100 | \$10 |
| | 90 | \$250 | \$25 |

RECHARGE DEVICES

Control measures which enhance the infiltration of urban runoff are indicated by the NURP studies to be techniques which are practical to apply and capable of effective reductions in urban runoff quantity and quality. This finding is based on project reports and on the results of a screening analysis using a probabilistic methodology described in a supplementary NURP document on detention basins.

The issue of the potential contamination of groundwater aquifers due to enhanced infiltration of urban storm runoff has been discussed in the previous chapter dealing with receiving water impacts. The favorable findings support further consideration of this technique. At the same time, it must be emphasized that specific local conditions may make recharge inappropriate. Such conditions can include steep slopes, soil conditions, depth to groundwater, and the proximity of water supply wells. Sound planning and engineering judgement must be applied to determine the acceptability of this control approach in a local situation.

However, where local conditions premit, a wide variety of design concepts are available for use. These range from off-site applications consisting of large retention basins, to small individual on-site units which include infiltration pits and trenches, percolating catch basins, and porous pavement. The operating principle is the same regardless of size or design concept. The important elements are the surface area provided for sub-surface percolation and the storage volume of the device. Overall performance will be related to the size of the recharge device relative to the urban catchment it serves and the permeability (infiltration rate) of the soil.

The context in which the performance capabilities of recharge devices are evaluated is the extent to which urban runoff is "captured" and prevented from discharging directly to surface waters. Pollutant removals are reduced in direct proportion to the runoff volume which is intercepted and recharged. Load reductions will be further enhanced if quality improvements occur in the portion of the runoff which is not captured. The combination of soil infiltration rate and percolating area provided determines the "treatment rate" of a specific recharge device. When storm runoff is applied to the device at rates of flow equal to or less than this rate, 100 percent of the runoff is captured during that event. At higher applied rates, the fraction of the runoff flow in excess of the treatment rate will escape and discharge to surface waters.

Most recharge devices other than porous pavement also provide storage volume. This improves performance capability because portions of the excess runoff can be retained for subsequent percolation when applied rates subside. Overflow to surface water occurs only when the available storage is exceeded.

The Long Island and Metropolitan Washington, D.C. (WASHCOG) NURP projects examined the performance of on-site recharge devices. An interconnected system of percolating catch basins in Long Island was estimated to reduce surface water discharges of storm runoff by more than 99 percent. The WASHCOG project found that a porous pavement site produced pollutant load reductions on the order of 85 to 95 percent depending on the specific pollutant considered. An infiltration trench studied by this project produced reductions in the order of 50 percent.

The NURP analysis methodology was employed in a screening analysis to assist planning evaluations by establishing the relationship between performance level and device size and soil percolation rates. Figure 8-4 presents a planning level estimate of the influence of size, soil characteristics, and regional rainfall differences on the performance of recharge devices.

The upper plot illustrates the significant effect regional differences in rainfall characteristics can have on the performance of identical recharge devices. Basin depth, soil percolation rate, and runoff coefficient for the urban catchment are the same for each case. The performance differences result from differences in the intensity and volume of the average storms in each region. Basin size is represented on the horizontal axis by expressing the percolation area that is provided as a percentage of the area of the contributing urban catchment. For example, a recharge device with a percolating surface area equal to 0.10 percent of an urban catchment represents a design which provides (43,560 sq ft/acre x 0.10/100% =) 43.5 square feet of

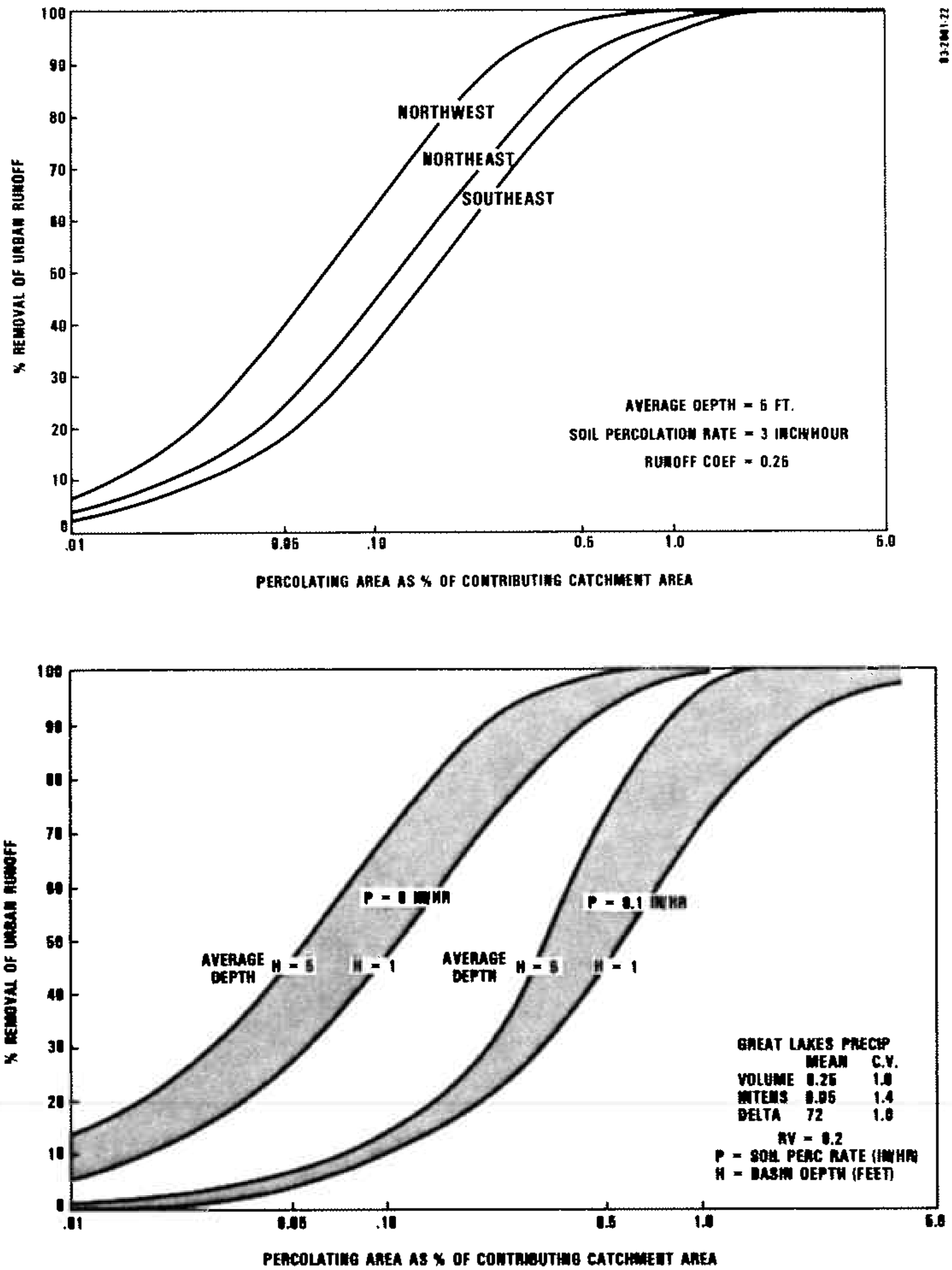



Figure 8-4. Long Term Average Performance of Recharge Devices

percolating surface area for each acre of urban catchment it serves. The long-term average reductions in urban runoff volume and pollutant load which can be expected will be approximately 35 percent in the southeast, 45 percent in the northeast and 65 percent in the Pacific northwest.

The lower plot illustrates the much more significant influence of the amount of storage volume provided (incidated by basin average depth), and the permeability of the soil through which the storm runoff must percolate. The rainfall characteristics used in this analysis are typical of the Great Lakes region of the United States and are roughly comparable to those in the northeastern part of the country. As might be expected, the permeability of the soil in which the recharge device is constructed has a dominant influence on performance capability. However significant compensation for low percolation rates can be achieved by increases in percolation area and storage volume.

When the screening analysis results are considered along with the favorable results from the NURP studies, the NURP findings indicate that with a reasonable degree of design flexibility to compensate for soils with lower percolation rates, recharge devices provide a very effective method for control of urban runoff.

## STREET SWEEPING

End-of-pipe urban runoff pollutant concentrations have been commonly viewed as being a function of two prime factors -- accumulation of contaminants on street surfaces and rainfall/runoff washoff. The postulated beneficial effect of street sweeping was to reduce contaminant accumulation. Prior to NURP, emphasis of street sweeping investigations was placed on street surface mechanisms (e.g., accumulation and washoff) and sweeper equipment performance in removing street dirt. While these studies provided valuable insights into the possible benefits of street sweeping, measurements of end-of-pipe concentrations are the only direct measures of street sweeping effectiveness in water quality terms.

Recognizing this, NURP was designed to provide a large data base of urban runoff water quality concentrations for both swept and unswept conditions. In addition, the NURP street sweeping projects gathered and evaluated data on atmospheric deposition (i.e., wetfall and dryfall), street surface accumulation and washoff, and street sweeper removal rates and costs. The individual project reports look at these other issues, and the results are not repeated herein. Of prime interest and provided below is the effectiveness of street sweeping in reducing end-of-pipe urban runoff pollutant concentrations (and ultimately receiving water impacts). The findings presented below are based upon the analyses performed by the individual projects, as well as other statistical techniques, and are generally consistent with the projects' conclusions.

Five of the 28 NURP prototype projects had the evaluation of street sweeping as a central element of their work plans. These projects were as follows:

| Project | Number of Sites |
|---|---|
| Castro Valley, CA | 1 |
| Milwaukee, WI | 8 |
| Champaign-Urbana, IL | 4 |
| Winston-Salem, NC | 2 |
| Bellevue, WA | 2 |

Long Island, NY and Baltimore, MD also collected limited street sweeping data. The experimental designs of the projects varied in detail, but essentially followed either a paired basin or serial basin approach to gather test and control data, with some projects using both approaches. The general concept was that during a test period street sweeping would be more intensive (up to daily) and thorough (e.g., with operator training, parking bans, etc.) than during control periods when the streets were to be swept as usual or not at all.

In the paired basin approach, two adjacent or close-by basins were operated in a "control" or unswept mode for certain periods of time to establish a baseline comparison, and then street sweeping was performed in a "test" basin while the other remained as a control. The data provided an overall comparison between basins as well as a series of synoptic events for both basins. In the serial approach, a basin was periodically operated in either a control or test mode, with the periods adjusted so that all seasons of the year were represented in each mode. Here, rather than synoptic data pairs, one has data strings for both "swept" and "unswept" conditions.

There are no well established or prescribed procedures for evaluating the possible reduction in runoff concentrations due to street sweeping. Issues of concern include storm size and intensity effects, time since last rain, ability to select truly paired basins, seasonal effects, etc. In an attempt to sort out these issues, an exploratory data analysis was performed, and the following findings were established:

- Street sweeping has not been found to change the basic probability distribution of event mean concentrations. That is, the fundamental assumption of random, lognormal behavior is valid during sweeping operations.

- The runoff quality characteristics of a basin during swept or unswept conditions is best measured by the maximum likelihood estimator of the median EMC, with the uncertainty indicated by the 90 percent confidence interval of the median.

- There is in most cases no significant correlation (and in a few cases a weak negative correlation) between EMCs and storm runoff volume. EMCs and storm runoff intensities are also generally uncorrelated (but in isolated cases exhibit a weak positive correlation). The implication of these findings is that differences in concentrations between swept and unswept conditions will be largely unaffected by the size of the storms during the monitoring periods. Because of this independence between concentration and volume, effects of sweeping on EMCs will also indicate effects on mass pollutant loads.

- EMCs for synoptic events on paired basins are, in general, not significantly correlated or in some cases are weakly correlated; however, over the longer term (e.g., mean, frequency distribution, etc.), there are no significant differences between the distribution of EMCs of paired basins. These results show that basins are independent from storm to storm, and thus, comparisons between basins should not be attempted using synoptic events, but the basins do have similar statistical properties and thus can be considered paired.

To evaluate the effectiveness of street sweeping, a series of bivariate plots were constructed for projects using the serial basin approach. The site median EMCs for swept and unswept conditions form the data pairs of the plots. Bivariate plots are presented in Figure 8-5 for TSS, COD, TP, TKN, and Pb concentrations, respectively. Each plot contains swept or unswept conditions for multiple project sites. The assumption of the analysis is that a large enough data base was collected to negate any temporal effects such as seasonal, land use conditions, parking patterns, and other possible factors (as noted earlier, storm volume and intensity effects are not believed to be significant). Examining the bivariate plots, it is observed that, for the NURP data, the median concentrations are as likely to be increased as decreased by street sweeping. Further, street sweeping never produced a dramatic (e.g., >50 percent) reduction in concentrations (or loads).

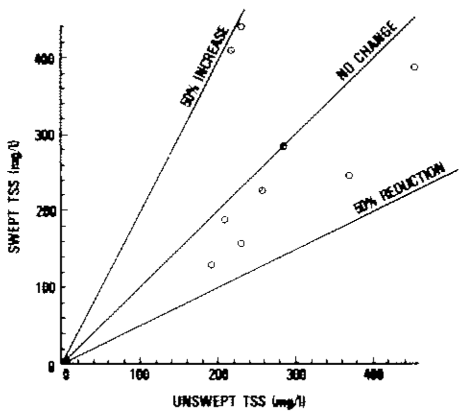
Street sweeping performance, as measured by the percent change in the site median EMC, for selected NURP sites is graphically displayed in Figure 8-6. The results are for five constituents (TSS, COD, TP, TKN, and Pb) at 10 sites nationwide). For each site, the median EMC is based on data from between 10 and 60 events, with 30 events typical. Based on Figure 8-6 a number of important observations are evident.

- Performance as measured by change in site median EMC is highly variable.

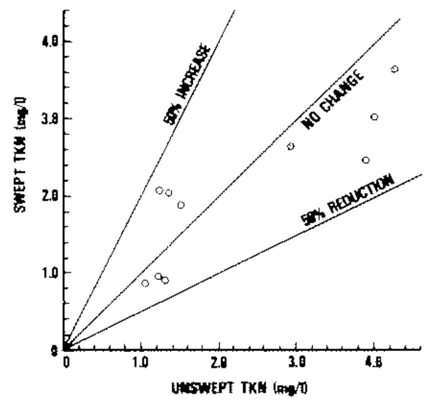
- Where reductions occur, they generally occur for all constituents.

- Reductions never exceed 50 percent.

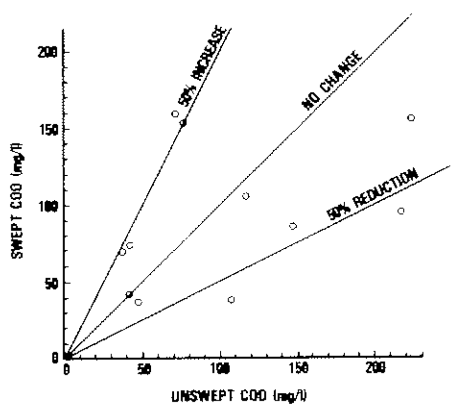
(TSS Concentrations)



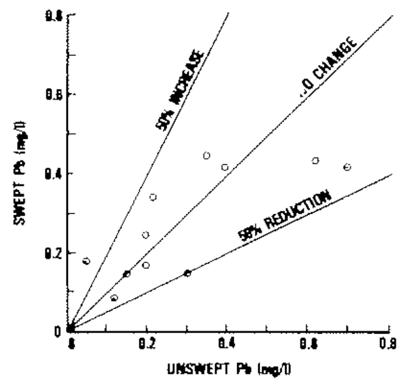

(TKN Concentrations)




(COD Concentrations)




(Pb Concentrations)




(TP Concentrations)

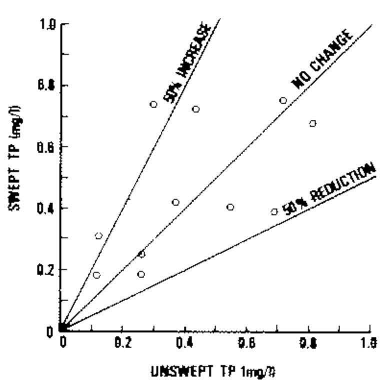



Figure 8-5. Bivariate Plots of Median EMCs for Swept and Unswept Conditions

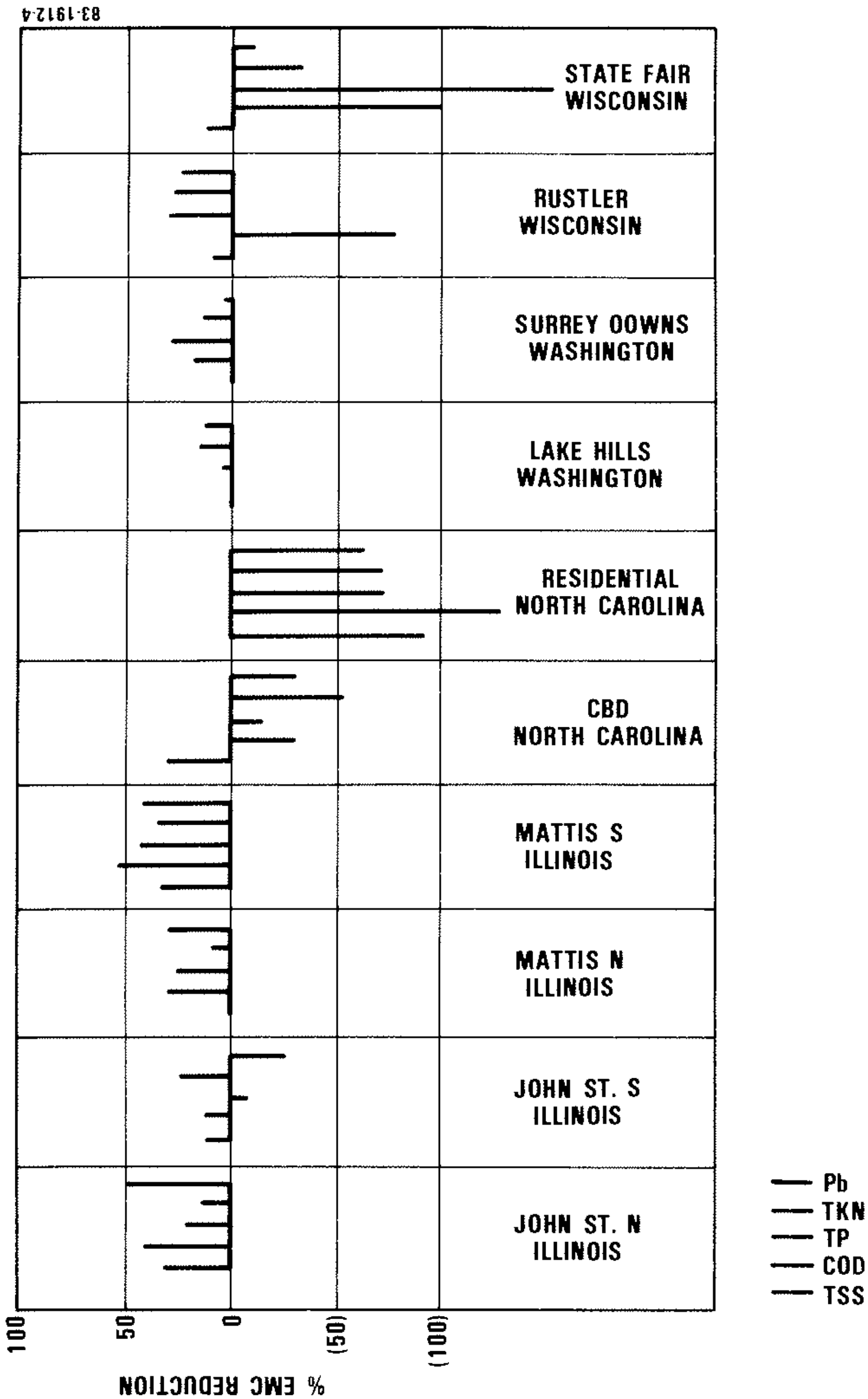



Figure 8-6. Street Sweeping Performance

In evaluating the results, it is critical that the uncertainty in the estimate of median EMCs based on limited observed data, and thus the uncertainty in performance estimates, be assessed. This is especially true for the cases of apparent increases in concentrations indicated by Figure 8-6.

For each of the 10 sites considered, the 90 percent confidence intervals of the site median EMCs were computed as indicated in Figure 8-7. This analysis indicates that there is generally no significant difference between median EMCs for swept and unswept conditions. The implications of this analysis of uncertainty are as follows:

- Based on statistical testing, no significant reductions in EMCs are realized by street sweeping.
- The indicated changes in site median EMCs (increases or decreases) are much more likely due to random sampling than actual effects of sweeping operations.
- Benefits of street sweeping (if any) are masked by the large variability of the EMCs, therefore the benefit is certainly not large (e.g., >50 percent), and an even larger site data base is required to further identify the possible effect.
- In the above context, the hypothesis that street sweeping increases EMCs is generally not shown by the data, though it could occur in isolated, site specific cases.

Urban runoff loads are the product of long term (e.g., annual) runoff volume and event mean concentration. Under this definition, statements concerning EMCs also hold for loads.

## OTHER CONTROL APPROACHES

Several best management practices (BMPs) in addition to those discussed above should be identified on the basis that local planning efforts determined them to be practical to apply and to have the potential to provide significant improvements in the quality characteristics of urban runoff. They are grouped together in this section and discussed only briefly, principally because, for one reason or another, sufficient data to characterize their performance capabilities was not developed during the NURP program.

### Grass Swales

Three grass swales were monitored by the Washington, D.C. area NURP project. No significant improvement is urban runoff quality was indicated for pollutants analyzed. Increases in zinc concentration which were observed were attributed to mobilization of zinc from the galvanized culverts which carried runoff under the driveways at the monitored residential sites. However the project study report concluded that modifications which would increase residence of runoff in the swales and enhance infiltration capability could make this BMP effective for control of urban runoff.

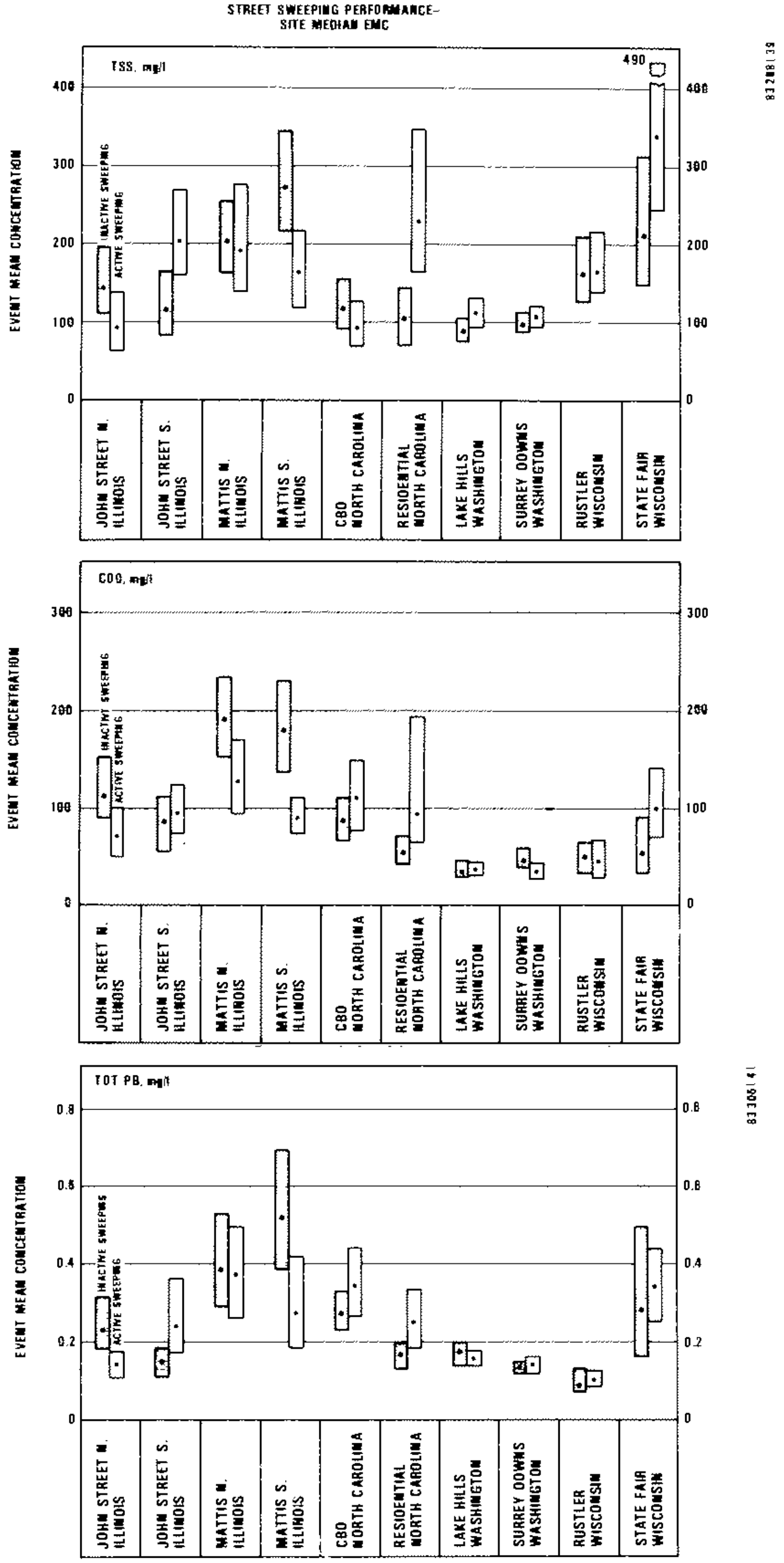



Figure 8-7. Effect of Street Sweeping on Site Median EMC Values

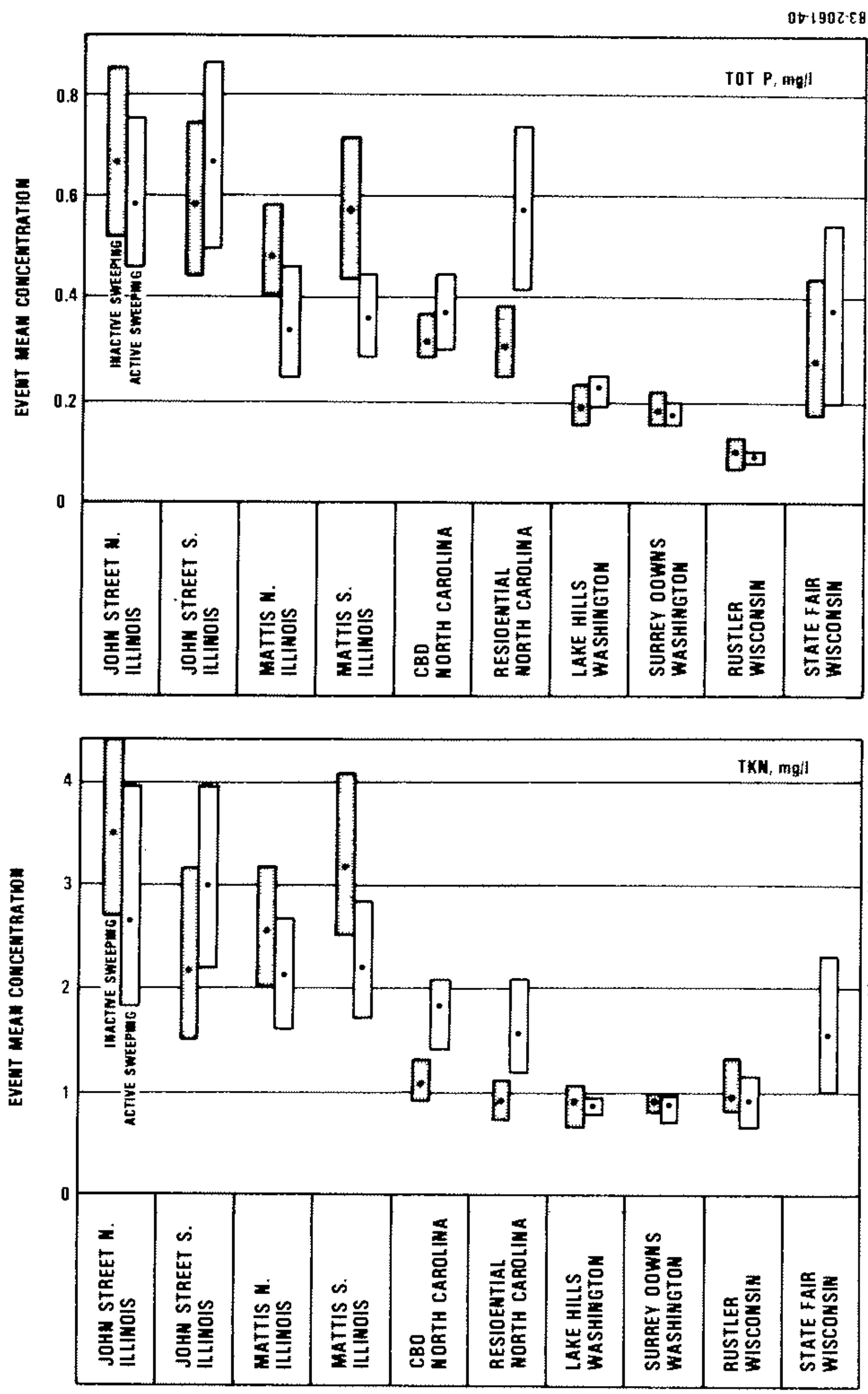



Figure 8-7. Effect of Street Sweeping on
Site Median EMC Values (Cont'd)

The Durham, New Hampshire NURP project monitored performance of a carefully designed artificial swale which received runoff from a commercial parking lot. Over 11 monitored storms, both soluble and particulate fractions of heavy metals (Cu, Pb, Zn, and Cd) were reduced by approximately 50 percent. Reductions in COD, nitrate, and ammonia were on the order of 25 percent. The swale did not prove to be effective in reducing concentrations or organic nitrogen, phosphorus, or bacterial species. It should be noted that the performance capabilities indicated are based only on the concentration changes produced in the stormwater which passes completely through the swale. To the extent that infiltration of a portion of the runoff is effected by a swale, load reductions would be increased in proportion.

The NURP results suggest that grass swales represent a practical and potentially effective technique for control of urban runoff quality; that design conditions are of major significance; and that additional study is necessary to establish such parameters.

Wetlands

The potential of either natural or artificially created wetland areas to effect favorable modification of urban runoff pollutant loads (particularly sediment, nutrients, and heavy metals) has been widely suggested. The NURP experience reinforces this expectation, but has not developed the detailed performance data to permit either characterizing general performance capabilities or identifying general design principles and parameters. Additional study will be required to develop such information.

Miscellaneous

This category encompasses a variety of BMPs which were identified at the local level as techniques of quality control which appeared to be relevant for the circumstances which were operative. They are grouped under this category because (a) their applicability tends to be site-specific rather than general, and (b) while their effectiveness as a BMP may be substantial on a relatively small spatial scale, the broad-scale effect on urban runoff loads has not been possible to document.

BMPs in this category include erosion control practices and urban housekeeping practices. As an example of the former, the Little Rock, Arkansas NURP project widened and stabilized (with rip rap) a segment of an urban stream to reduce erosion potential. The Baltimore NURP project data clearly indicated the substantial difference in urban runoff quality that can result from the general level of cleanliness maintained in an urban neighborhood.

# CHAPTER 9
# CONCLUSIONS

## INTRODUCTION

The Nationwide Urban Runoff Program has addressed such issues as quantifying the characteristic of urban runoff, assessing the water quality effects on receiving water bodies attributable to urban runoff discharges, and examining the effectiveness of control practices in removing the pollutants found in urban runoff. This chapter summarizes NURP's conclusion relating to these issues and is based on the results presented in Chapters 6, 7, and 8 of this report. Conclusions reached by the individual NURP projects are also presented to further support the results of the national level analysis.

## URBAN RUNOFF CHARACTERISTICS

### General

Field monitoring was conducted to characterize urban runoff flows and pollutant concentrations. This was done for a variety of pollutants at a substantial number of sites distributed throughout the country. The resultant data represent a cross-section of regional climatology, land use types, slopes, and soil conditions and thereby provide a basis for identifying patterns of similarities or differences and testing their significance.

Urban runoff flows and concentrations of contaminants are quite variable. Experience shows that substantial variations occur within a particular event and from one event to the next at a particular site. Due to the high variability of urban runoff, a large number of sites and storm events were monitored, and a statistical approach was used to analyze the data. Procedures are available for characterizing variable data without requiring knowledge of or existence of any underlying probability distribution (nonparametric statistical procedures). However, where a specific type of probability distribution is known to exist, the information content and efficiency of statistical analysis is enhanced. Standard statistical procedures allowed probability distributions or frequency of occurrence to be examined and tested. Since the underlying distributions were determined to be adequately represented by the lognormal distribution, the log (base e) transforms of all urban runoff data were used in developing the statistical characterizations.

The event mean concentration (EMC), defined as the total constituent mass discharge divided by the total runoff volume, was chosen as the primary water quality statistic. Event mean concentrations were based on flow weighted composite samples for each event at each site in the accessible data base. EMCs were chosen as the primary water quality characteristic subjected to detailed analysis, even though it is recognized that mass loading characteristics of urban runoff (e.g., pounds/acre for a specified time interval) is ultimately the relevant factor in many situations. The reason is that, unlike EMCs, mass loadings are very strongly influenced by the amount of precipitation and runoff, and estimates of typical annual mass loads will be biased by the size of monitored storm events. The most reliable basis for characterizing annual or seasonal mass loads is on the basis of EMC and site-specific rainfall/runoff characteristics.

Establishing the fundamental distribution as lognormal and the availability of a sufficiently large population of EMCs to provide reliability to the statistics derived has yielded a number of benefits, including the ability to provide:

- Concise summaries of highly variable data

- Meaningful comparisons of results from different sites, events, etc.

- Statements concerning frequency of occurrence. One can express how often values will be expected to exceed various magnitudes of interest.

- A more useful method of reporting data than the use of ranges; one which is less subject to misinterpretation

- A framework for examining "transferability" of data in a quantitative manner

Conclusions

1. Heavy metals (especially copper, lead and zinc) are by far the most prevalent priority pollutant constituents found in urban runoff. End-of-pipe concentrations exceed EPA ambient water quality criteria and drinking water standards in many instances. Some of the metals are present often enough and in high enough concentrations to be potential threats to beneficial uses.

   All 13 metals on EPA's priority pollutant list were detected in urban runoff samples, and all but three at frequencies of detection greater than 10 percent. Most often detected among the metals were copper, lead, and zinc, all of which were found in at least 91 percent of the samples.

   Metal concentrations in end-of-pipe urban runoff samples (i.e., before dilution by receiving water) exceeded EPA's water quality criteria and drinking water standards numerous times. For example, freshwater acute criteria were exceeded by copper concentrations in 47 percent of the samples and by lead in 23 percent. Freshwater chronic exceedances were common for lead (94 percent), copper (82 percent), zinc (77 percent), and cadmium (48 percent). Regarding human toxicity, the most significant pollutants were lead and nickel, and for human carcinogenesis, arsenic and beryllium. Lead concentrations violated drinking water criteria in 73 percent of the samples.

It should be stressed that the exceedances noted above do not necessarily imply that an actual violation of standards will exist in the receiving water body in question. Rather, the enumeration of exceedances serves a screening function to identify those heavy metals whose presence in urban runoff warrants high priority for further evaluation.

Based upon the much more extensive NURP data set for total copper, lead, and zinc, the site median EMC values for the median urban site are: Cu = 34 µg/l, Pb = 144 µg/l, and Zn = 160 µg/l. For the 90th percentile urban site the values are: Cu = 93 µg/l, Pb = 350 µg/l, and Zn = 500 µg/l. These values are suggested to be appropriate for planning level screening analyses where data are not available.

Some individual NURP project sites (e.g., at DC1, MD1, NH1) found unusually high concentrations of certain heavy metals (especially copper and zinc) in urban runoff. This was attributed by the projects to the effect of acid rain on materials used for gutters, culverts, etc.

2. <u>The organic priority pollutants were detected less frequently and at lower concentrations than the heavy metals.</u>

Sixty-three of a possible 106 organics were detected in urban runoff samples. The most commonly found organic was the plasticizer bis (2-ethylhexl) phthalate (22 percent), followed by the pesticide α-hexachlorocyclohexane (α-BHC) (20 percent). An additional 11 organic pollutants were reported at frequencies between 10 and 20 percent; 3 pesticides, 3 phenols, 4 polycyclic aromatics, and a single halogenated aliphatic.

Criteria exceedances were less frequently observed among the organics than the heavy metals. One unusually high pentachlorophenol concentration of 115 µg/l resulted in exceedances of the freshwater acute and organoleptic criteria. This observation and one for chlordane also exceeded the freshwater acute criteria. Freshwater chronic criteria exceedances were observed for pentachlorophenol, bis (2-ethylhexyl) phthalate, gamma-BHC, chlordane, and alpha-endosulfan. All other organic exceedances were in the human carcinogen category and were most serious for alpha-hexachlorocyclohexane (alpha-BHC), gamma-hexachlorocyclohexane (gamma-BHC or Lindane), chlordane, phenanthrene, pyrene, and chrysene.

The fact that the NURP priority pollutant monitoring effort was limited to two samples at each site leaves us unable to make many generalizations about those organic pollutants which occurred only rarely. We can speculate that their occurrences tend to be very site specific as opposed to being a generally widespread phenomena, but much more data would be required to conclusively prove this point.

3. <u>Coliform bacteria are present at high levels in urban runoff and can be expected to exceed EPA water quality criteria during and immediately after storm events in many surface waters, even those providing high degrees of dilution.</u>

Fecal coliform counts in urban runoff are typically in the tens to hundreds of thousand per 100 ml during warm weather conditions, with the median for all sites being around 21,000/100 ml. During cold weather, fecal coliform counts are more typically in the 1,000/100 ml range, which is the median for all sites. Thus, violations of fecal coliform standards were reported by a number of NURP projects. High fecal coliform counts may not cause actual use impairments, in some instances, due to the location of the urban runoff discharges relative to swimming areas or shellfish beds and the degree of dilution/dispersal and rate of die off. The same is true of total coliform counts, which were found to exceed EPA water quality criteria in undiluted urban runoff at virtually every site every time it rained.

The substantial seasonal differences noted above do not correspond with comparable variations in urban activities. The NURP analyses as well as current literature suggest that fecal coliform may not be the most appropriate indicator organism for identifying potential health risks when the source is stormwater runoff.

4. Nutrients are generally present in urban runoff, but with a few individual site exceptions, concentrations do not appear to be high in comparison with other possible discharges to receiving water bodies.

   NURP data for total phosphorus, soluble phosphorus, total kjeldahl nitrogen, and nitrate plus nitrite as nitrogen were carefully examined. Median site EMC median concentrations in urban runoff were TP = 0.33 mg/l, SP = 0.12 mg/l, TKN = 1.5 mg/l, and NO2+3 - N = 0.68 mg/l. On an annual load basis, comparison with typical monitoring data, literature values, and design objectives for discharges from a well run secondary treatment plant suggests that mean annual nutrient loads from urban runoff are around an order of magnitude less than those from a POTW.

5. Oxygen demanding substances are present in urban runoff at concentrations approximating those in secondary treatment plant discharges. If dissolved oxygen problems are present in receiving waters of interest, consideration of urban runoff controls as well as advanced waste treatment appears to be warranted.

   Urban runoff median site EMC median concentrations of 9 mg/l BOD5 and 65 mg/l COD are reflected in the NURP data, with 90th percentile site EMC median values being 15 mg/l BOD5 and 140 mg/l COD. These concentrations suggest that, on an annual load basis, urban runoff is comparable in magnitude to secondary treatment plant discharges.

   It can be argued that urban runoff is typically well oxygenated and provides increased stream flow and, hence, in view of relatively long travel times to the critical point, that dissolved oxygen problems attributable solely to urban runoff should not be widespread occurrences. No NURP project specifically identified a low DO condition resulting from urban runoff. Nonetheless, there will be some situations where consideration of urban runoff controls for oxygen demanding substances in an overall water quality management strategy would seem appropriate.

6. Total suspended solids concentrations in urban runoff are fairly high in comparison with treatment plant discharges. Urban runoff control is strongly indicated where water quality problems associated with TSS, including build-up of contaminated sediments, exist.

   There are no formal water quality criteria for TSS relating to either human health or aquatic life. The nature of the suspended solids in urban runoff is different from those in treatment plant discharges, being higher in mineral and man-made products (e.g., tire and street surface wear particles) and somewhat lower in organic particulates. Also, the solids in urban runoff are more likely to have other contaminants adsorbed onto them. Thus, they cannot be simply considered as benign, nor do they only pose an aesthetic issue. NURP did not examine the problem of contaminated sediment build-up due to urban runoff, but it undeniably exists, at least at some locations.

   The suspended solids in urban runoff can also exert deleterious physical effects by sedimenting over egg deposition sites, smothering juveniles, and altering benthic communities.

   On an annual load basis, suspended solids contributions from urban runoff are around an order of magnitude or more greater than those from secondary treatment plants. Control of urban runoff, as opposed to advanced waste treatment, should be considered where TSS-associated water quality problems exist.

7. A summary characterization of urban runoff has been developed and is believed to be appropriate for use in estimating urban runoff pollutant discharges from sites where monitoring data are scant or lacking, at least for planning level purposes.

   As a result of extensive examination, it was concluded that geographic location, land use category (residential, commercial, industrial park, or mixed), or other factors (e.g., slope, population density, precipitation characteristics) appear to be of little utility in consistently explaining overall site-to-site variability in urban runoff EMCs or predicting the characteristics of urban runoff discharges from unmonitored sites. Uncertainty in site urban runoff characteristics caused by high event-to-event variability at most sites eclipsed any site-to-site variability that might have been present. The finding that EMC values are essentially not correlated with storm runoff volumes facilitates the transfer of urban runoff characteristics to unmonitored sites. Although there tend to be exceptions to any generalization, the suggested summary urban runoff characteristics given in Table 6-17 of the report are recommended for planning level purposes as the best estimates, lacking local information to the contrary.

## RECEIVING WATER EFFECTS

### General

The effects of urban runoff on receiving water quality are highly site-specific. They depend on the type, size, and hydrology of the water body; the urban runoff quantity and quality characteristics; the designated beneficial use; and the concentration levels of the specific pollutants that affect that use.

The conclusions which follow are based on screening analyses performed by NURP, observations and conclusions drawn by individual NURP projects that examined receiving water effects in differing levels of detail and rigor, and NURP's three levels of problem definition. Conclusions are organized on the basis of water body type: rivers and streams, lakes, estuaries and embayments, and groundwater aquifers. Site-specific exceptions should be expected, but the statements presented are believed to provide an accurate perspective on the general tendency of urban runoff to contribute significantly to water quality problems.

### Rivers and Streams

1. <u>Frequent exceedances of heavy metals ambient water quality criteria for freshwater aquatic life are produced by urban runoff</u>.

   The Denver NURP project found that in-stream concentrations of copper, lead, zinc, and cadmium exceeded State ambient water quality standards for the South Platte River during essentially all storm events.

   NURP screening analyses suggest that frequent exceedances of both EPA 24-hour and maximum water quality criteria for heavy metals should be expected on a relatively general basis.

2. <u>Although a significant number of problem situations could result from heavy metals in urban runoff, levels of freshwater aquatic life use impairment suggested by the magnitude and frequency of ambient criteria exceedances were not observed</u>.

   Based upon the magnitude and frequency of freshwater aquatic life ambient criteria exceedances, one would expect to observe impairment of this beneficial use in most streams that receive urban runoff discharges. However, those NURP project studies which examined this issue did not report significant use impairment problems associated with urban runoff.

   The Bellevue, Washington NURP project concluded that toxic effects of urban runoff pollutants did not appear to be a significant factor.

   The Tampa, Florida NURP project conducted biological studies of the impact of stormwater runoff upon the biological community of the Hillsborough River. They conducted animal bioassay experiments on five sensitive species in two samples of urban runoff from the Arctic Street drainage basin. Thirty-two bioassay experiments were completed including 22 acute tests and 10 chronic tests. Neither sample of stormwater was acutely toxic to test organisms. Long-term chronic experiments were undertaken with two species and resulted in no significant effects attributable to stormwater exposure.

NURP screening analyses suggest that the potential of urban runoff to seriously impair this beneficial use will be strongly influenced by local conditions and the frequency of occurrence of concentration levels which produce toxic effects under the intermittent, short duration exposures typically produced by urban runoff.

While the application of the screening analysis to the Bellevue and Tampa situations supports the absence of a problem situation in these cases, it also suggests that a significant number of problem situations should be expected. Therefore, although not the general, ubiquitous problem situation that criteria exceedances would suggest, there are site-specific situations in which urban runoff could be expected to cause significant impairment of freshwater aquatic life uses.

Because of the inconsistency between criteria exceedances and observed use impairments due to urban runoff, adaptation of current ambient quality criteria to better reflect use impacts where pollutant exposures are intermittent and short duration appears to be a useful area for further investigation.

3. <u>Copper, lead and zinc appear to pose a significant threat to aquatic life uses in some areas of the country. Copper is suggested to be the most significant of the three.</u>

   Regional differences in surface water hardness, which has a strong influence on toxicity, in conjunction with regional variations in stream flow and rainfall result in significant differences in susceptibility to adverse impacts around the nation.

   The southern and southeastern regions of the country are the most susceptible to aquatic life effects due to heavy metals, with the northeast also a sensitive area, although somewhat less so.

   Copper is the major toxic metal in urban runoff, with lead and zinc also prevalent but a problem in more restricted cases. Copper discharges in urban runoff are, in all but the most favorable cases, a significant threat to aquatic life uses in the southeast and southern regions of the country. In the northeast, problems would be expected only in rather unfavorable conditions (large urban area contribution and high site concentrations). In the remainder of the country (and for the other metals) problems would only be expected under quite unfavorable site conditions. These statements are based on total metal concentrations.

4. <u>Organic priority pollutants in urban runoff do not appear to pose a general threat to freshwater aquatic life.</u>

   This conclusion is based on limited data on the frequency with which organics are found in urban runoff discharges and measured end-of-pipe concentrations relative to published toxic criteria. One unusually high pentachlorophenol concentration of 115 μg/l resulted in the only exceedance of the organoleptic criteria. This observation and one for chlordane exceeded the freshwater acute criteria. Freshwater chronic criteria exceedances were observed for pentochlorophenol, bis (2-ethylhexyl) phlhalate, γ-hexachlorocyclohexane (lindane), α-endosulfan, and chlordane.

5. The physical aspects of urban runoff, e.g., erosion and scour, can be a significant cause of habitat disruption and can affect the type of fishery present. However, this area was studied only incidentally by several of the projects under the NURP program and more concentrated study is necessary.

The Metropolitan Washington Council of Governments (MWCOG) NURP project did an analysis of fish diversity in the Seneca Creek Watershed, 20 miles northwest of Washington, D.C. In this study, specific changes in fishery diversity were identified due to urbanization in some of the sub-watersheds. Specifically, the number of fish species present are reduced and the types of species present changed dramatically, e.g., environmentally sensitive species were replaced with more tolerant species. For example, the Blacknose Dace replaced the Mottled Sculpin. MWCOG concluded that the changes in fish diversity were due to habitat deterioration caused by the physical aspects of urban runoff.

The Bellevue, Washington NURP project concluded that habitat changes (streambed scour and sedimentation) had a more significant effect than pollutant concentrations, for the changes produced by urbanization.

6. Several projects identified possible problems in the sediments because of the build-up of priority pollutants contributed wholly or in part by urban runoff. However, the NURP studies in this area were few in number and limited in scope, and the findings must be considered only indicative of the need for further study, particularly as to long-term impacts.

The Denver NURP project found significant quantities of copper, lead, zinc, and cadmium in river sediments. The Denver Regional Council of Governments is concerned that during periods of continuous low flow, lead may reach levels capable of adversely affecting fish.

The Milwaukee NURP project reported the observation of elevated levels of heavy metals, particularly lead, in the sediments of a river receiving urban runoff.

7. Coliform bacteria are present at high levels in urban runoff and can be expected to exceed EPA water quality criteria during and immediately after storm events in most rivers and streams.

Violations of the fecal coliform standard were reported by a number of NURP projects. In some instances, high fecal coliform counts may not cause actual use impairments due to the location of the urban runoff discharge relative to swimming areas and the degree of dilution or dispersal and rate of die off.

Coliform bacteria are generally accepted to be a useful indicator of the possible presence of human pathogens when the source of contamination is sanitary sewage. However, no such relationship has been demonstrated for urban runoff. Therefore, the use of coliforms as an indicator of human health risk when the sole source of contamination is urban runoff, warrants further investigation.

8. Domestic water supply systems with intakes located on streams in close proximity to urban runoff discharges are encouraged to check for priority pollutants which have been detected in urban runoff, particularly those in the organic category.

   Sixty-three of a possible 106 organics were detected in urban runoff samples. The most commonly found organic was the plasticizer bis (2-ethylhexl) phthalate (22 percent), followed by the pesticide α-hexachlorocyclohexane (α-BHC) (20 percent). An additional 11 organic pollutants were reported at frequencies between 10 and 20 percent; 3 pesticides, 3 phenols, 4 polycyclic aromatics, and a single halogenated aliphatic.

Lakes

1. Nutrients in urban runoff may accelerate eutrophication problems and severely limit recreational uses, especially in lakes. However, NURP's lake projects indicate that the degree of beneficial use impairment varies widely, as does the significance of the urban runoff component.

   The Lake Quinsigamond NURP project in Massachusetts identified eutrophication as a major problem in the lake, with urban runoff being a prime contributor of the critical nutrient phosphorus. Point source discharges to the lake have been eliminated almost entirely. However, in spite of the abatement of point sources, survey data indicate that the lake has shown little improvement over the abatement period. In particular, the trophic status of the lake has shown no change, i.e., it is still classified as late mesotrophic-early eutrophic. Substantial growth is projected in the basin, and there is concern that Lake Quinsigamond will become more eutrophic. A proposed water quality management plan for the lake includes the objective of reducing urban runoff pollutant loads.

   The Lake George NURP project in New York State also identified increasing eutrophication as a potential problem if current development trends continue. Lake George is not classified as eutrophic, but from 1974 to 1978 algae production in the lake increased logarithmically. Lake George is a very long lake, and the limnological differences between the north and south basins provide evidence of human impact. The more developed, southern portion of the lake exhibits lower transparencies, lower hypolimnetic dissolved oxygen concentrations, higher phosphorus and chlorophyll *a* concentrations, and a trend toward seasonal blooms of blue-green algae. These differences in water quality indicators are associated with higher levels of cultural activities (e.g., increased sources of phosphorus) in the southern portion of the lake's watershed, and continued development will tend to accentuate the differences.

The Lake George NURP project estimated that urban runoff from developed areas currently accounts for only 13.6 percent of the annual phosphorus loadings to Lake George as a whole. In contrast, developed areas contribute 28.9 percent of the annual phosphorus load to the NURP study areas at the south end of the Lake. Since there are no point source discharges, this phosphorus loading is due solely to urban runoff. These data illustrate the significant impact of urbanization on phosphorus loads.

The NURP screening analysis suggests that lakes for which the contributions of urban runoff are significant in relation to other nonpoint sources (even in the absence of point source discharges) are indicated to be highly susceptible to eutrophication and that urban runoff control may be warranted in such situations.

2. Coliform bacteria discharges in urban runoff have a significant negative impact on the recreational uses of lakes.

As was the case with rivers and streams, coliform bacteria in urban runoff can cause violations of criteria for the recreational use of lakes. When unusually high fecal coliform counts are observed, they may be partially attributable to sanitary sewage contamination, in which case significant health risks may be involved.

The Lake Quinsigamond NURP project in Massachusetts found that bacterial pollution was widespread throughout the drainage basin. In all cases where samples were taken, fecal coliforms were in excess of 10,000 counts per 100 ml, with conditions worse in the Belmont street storm drains. This project concluded that the very high fecal coliform counts in their stormwater are at least partially due to sewage contamination apparently entering the stormwater system throughout the local catchment.

The sources of sewage contamination are leaking septic tanks, infiltration from sanitary sewers into storm sewers, and leakage at manholes. In the northern basin, the high fecal coliform counts are attributed to known sewage contamination sources on Poor Farm Brook. The data from the project suggest that it would be unwise to permit body contact recreation in the northern basin of the lake during or immediately following significant storm events. The project concluded that disinfection at selected storm drains should be considered in the future, especially if the sewage contamination cannot be eliminated.

The Mystic River NURP project in Massachusetts found various areas where fecal coliform counts were extremely high in urban stormwater. Fecal coliform levels of up to one million with an average of 178,000/100 ml were recorded in Sweetwater Brook, a tributary to Mystic River, during wet weather. These high fecal coliform levels were specifically attributed to surcharging in their sanitary sewers, which caused sanitary sewage to overflow into their storm drains via the combined manholes present in this catchment. Fecal coliform levels above the class B fecal coliform standard of 200 per 100 ml were found in approximately one-third of the samples tested in the upper and lower forebays of the Upper Mystic Lake and occasionally near the lake's outlet. In addition, Sandy Beach, a public swimming area on Upper Mystic Lake, exceeded the State fecal coliform criteria in July of 1982, and warnings that swimming may be hazardous to public health were posted for several days. It is important to note that sewage contamination of surface waters is a major problem in the watershed. The project concluded that urban runoff contributes to the bacteria load during wet weather but, comparatively, is much less significant than the sanitary sources.

Estuaries and Embayments

1. Adverse effects of urban runoff in marine waters will be a highly specific local situation. Though estuaries and embayments were studied to a very limited extent in NURP, they are not believed to be generally threatened by urban runoff, though specific instances where use is impaired or denied can be of significant local and even regional importance. Coliform bacteria present in urban runoff is the primary pollutant of concern, causing direct impacts on shellfish harvesting and beach closures.

   The significant impact of urban runoff on shellfish harvesting has been well documented by the Long Island, New York NURP project. In this project, stormwater runoff was identified as the major source of bacterial loading to marine waters and, thus, the indirect cause of the denial of certification by the New York State Department of Conservation for about one-fourth of the shellfishing area. Much of this area is along the south shore, where the annual commercial shellfish harvest is valued at approximately $17.5 million.

   The Myrtle Beach, South Carolina NURP project found that stormwater discharges from the City of Myrtle Beach directly onto the beach showed high bacterial counts for short durations immediately after storm events. In many instances these counts violated EPA water quality criteria for aquatic life and contact recreation. The high bacteria counts, however, were associated with standing pools formed at the end of collectors for brief periods following the cessation of rainfall and before the runoff percolated into the sand. Consequently, the threat to public health was not considered great enough to warrant closure of the beach.

Groundwater Aquifers

1. Groundwater aquifers that receive deliberate recharge of urban runoff do not appear to be imminently threatened by this practice at the two locations where it was investigated.

   Two NURP projects (Long Island and Fresno) are situated over sole source acquifers. They have been practicing recharge with urban runoff for two decades or more at some sites, and extensively investigated the impact of this practice on the quality of their groundwater. They both found that soil processes are efficient in retaining urban runoff pollutants quite close to the land surface, and concluded that no change in the use of recharge basins is warranted.

   Despite the fact that some of these basins have been in service for relatively long periods of time and pollutant breakthrough of the upper soil layers has not occurred, the ability of the soil to continue to retain pollutants is unknown. Further attention to this issue is recommended.

## CONTROL EFFECTIVENESS

### General

A limited number of techniques for the control of urban runoff quality were evaluated by the NURP program. The set is considerably smaller than previously published lists of potential management practices. Since the control approaches that were investigated were selected at the local level, the choices may be taken as an initial indication of local perceptions regarding practicality and feasibility from the standpoint of implementation.

### Conclusions

1. There is a strong preference for detention devices, street sweeping, and recharge devices as reflected by the control measures selected at the local level for detailed investigation. Interest was also shown in grass swales and wetlands.

   Six NURP projects monitored the performance of a total of 14 detention devices. Five separate projects conducted in-depth studies of the effectiveness of street sweeping on the control of urban runoff quality. A total of 17 separate study catchments were involved in this effort. Three NURP projects examined either the potential of recharge devices to reduce discharges of urban runoff to surface waters or the potential of the practice to contaminate groundwaters. A total of 12 separate sites were covered by this effort.

   Grass swales were studied by two NURP projects. Two swales in existing residential areas, and one experimental swale constructed to serve a commercial parking lot were studied.

   A number of NURP projects indicated interest in wetlands for improving urban runoff quality at early stages of the program. Only one allocated monitoring activity to this control measure, however.

   Various other management practices were identified as having local interest by individual NURP projects, but none of them was allocated the necessary resources to be pursued to a point which allowed an evaluation of their ability to control pollution from urban runoff. Management practices in this category included urban housekeeping (e.g., litter programs, catch basin cleaning, pet ordinances) and public information programs.

2. Detention basins are capable of providing very effective removal of pollutants in urban runoff. Both the design concept and the size of the basin in relation to the urban area served have a critical influence on performance capability.

   Wet basins (designs which maintain a permanent water pool) have the greatest performance capabilities. Observed pollutant reductions varied from excellent to very poor in the basins which were monitored. However, when basins are adequately sized, particulate removals in excess of 90 percent (TSS, lead) can be obtained. Pollutants with significant soluble fractions in urban runoff show lower reductions; on the order of 65 percent for total P and approximately 50 percent for BOD, COD, TKN, Copper, and Zinc. Results indicate that biological processes which are operative in the permanent pool produce significant reductions (50 percent or more) in soluble nutrients, nitrate and soluble phosphorus. These performance characteristics are indicated by both the NURP analysis results and conclusions reached by individual projects.

Dry basins, (conventional stormwater management basins), which are designed to attenuate peak runoff rates and hence only very briefly detain portions of flow from the larger storms, are indicated by NURP data to be essentially ineffective for reducing pollutant loads.

Dual-purpose basins (conventional dry basins with modified outlet structures which significantly extend detention time) are suggested by limited NURP data to provide effective reductions in urban runoff loads. Performance may approach that of wet ponds; however, the additional processes which reduce soluble nutrient forms do not appear to be operative in these basins. This design concept is particularly promising because it represents a cost effective approach to combining flood control and runoff quality control and because of the potential for converting existing conventional stormwater management ponds.

Approximate costs of wet pond designs are estimated to be in the order of \$500 to \$1500 per acre of urban area served, for on-site applications serving relatively small urban areas, and about \$100 to \$250 per acre of urban area for off-site applications serving relatively large urban areas. The costs reflect present value amounts which include both capital and operating costs. The difference is due to an economy of scale associated with large basin volumes. The range reflects differences in size required to produce particulate removals in the order of 50 percent or 90 percent. Annual costs per acre of urban area served are estimated at \$60 to \$175, and \$10 to \$25 respectively.

3. <u>Recharge Devices are capable of providing very effective control of urban runoff pollutant discharges to surface waters. Although continued attention is warranted, present evidence does not indicate that significant groundwater contamination will result from this practice.</u>

Both individual project results and NURP screening analyses indicate that adequately sized recharge devices are capable of providing high levels of reduction in direct discharges of urban runoff to surface waters. The level of performance will depend on both the size of the unit and the soil permeability.

Application will be restricted to areas where conditions are favorable. Soil type, depth to groundwater, land slopes, and proximity of water supply wells will all influence the appropriateness of this control technique.

Surface accumulations which result from the high efficiency of soils to retain pollutants, suggest further attention in applications where dual purpose recharge areas also serve as recreational fields or playground areas.

4. <u>Street sweeping is generally ineffective as a technique for improving the quality of urban runoff.</u>

Five NURP projects evaluated street sweeping as a management practice to control pollutants in urban runoff. Four of these projects concluded that street sweeping was not effective for this purpose. The fifth, which had pronounced wet and dry seasons, believed that sweeping just prior to the rainy season could produce some benefit in terms of reduced pollution in urban runoff.

A large data base on the quality of urban runoff from street sweeping test sites was obtained. At 10 study sites selected for detailed analysis, a total of 381 storm events were monitored under control conditions, and an additional 277 events during periods when street sweeping operations were in effect. Analysis of these data indicated that no significant reductions in pollutant concentrations in urban runoff were produced by street sweeping.

There may be special cases in which street cleaning applied at restricted locations or times of year could provide improvements in urban runoff quality. Some examples that have been suggested, though not demonstrated by the NURP program, include periods following snow melt or leaf fall, or urban neighborhoods where the general level of cleanliness could be significantly improved.

5. <u>Grass swales can provide moderate improvements in urban runoff quality. Design conditions are important. Additional study could significantly enhance the performance capabilities of swales.</u>

Concentration reductions of about 50 percent for heavy metals, and 25 percent for COD, nitrate, and ammonia were observed in one of the swales studied. However the swale was ineffective in reducing concentrations of organic nitrogen, phosphorus, or bacterial species. Two other swales studied failed to demonstrate any quality improvements in the urban runoff passing through them.

Evaluations by the NURP projects involved concluded, however, that this was an attractive control technique whose performance could be improved substantially by application of appropriate design considerations. Additional study to develop such information was recommended.

Design considerations cited included slope, vegetation type and maintenance, control of flow velocity and residence time, and enhancement of infiltration. The latter factor could produce load reductions greater than those inferred from concentration changes and effect reductions in those pollutant species which are not attenuated by flow through the swale.

6. <u>Wetlands are considered to be a promising technique for control of urban runoff quality. However, neither performance characteristics nor design characteristics in relation to performance were developed by NURP.</u>

   Although a number of projects indicated interest, only one assigned NURP monitoring activity to a wetland. This was a natural wetland, and flows passing though it were uncontrolled. Results suggest its potential to improve quality, but the investigation was not adequate to associate necessary design factors to performance capability. Additional attention to this control technique would be useful, and should include factors such as the need for maintenance harvesting to prevent constituent recycling.

ISSUES

A number of issues with respect to managing and controlling urban runoff emerge from the conclusions summarized above. In some instances they represent the need for additional data/information or for further study. In others they point to the need for follow-up activity by EPA, State, or local officials to assemble and disseminate what is already known regarding water quality problems caused by urban runoff and solutions.

<u>Sediments</u>

The nature and scope of the potential long-term threat posed by nutrient and toxic pollutant accumulation in the sediments of urban lakes and streams requires further study. A related issue is the safe and environmentally sound disposal of sediments collected in detention basins used to control urban runoff.

<u>Priority Pollutants</u>

NURP clearly demonstrated that many priority pollutants can be found in urban runoff and noted that a serious human health risk could exist when water supply intakes are in close proximity to urban stormwater discharges. However, questions related to the sources, fate, and transport mechanisms of priority pollutants borne by urban runoff and their frequencies of occurrence will require further study.

<u>Rainfall pH Effects</u>

The relationship between pH and heavy metal values in urban runoff has not been established and needs further study. Several NURP projects (mostly in the northeastern states) attributed high heavy metals concentrations in urban runoff to the effects of acid rain. Although it is quite plausible that acid rain increases the level of pollutants in urban runoff and may transform them to more toxic and more easily assimilated forms, further study is required to support this speculation.

<u>Industrial Runoff</u>

No truly industrial sites (as opposed to industrial parks) were included in any of the NURP projects. A very limited body of data suggests, however, that runoff from industrial sites may have significantly higher contaminant levels than runoff from other urban land use sites, and this issue should be investigated further.

### Central Business Districts

Data on the characteristics of urban runoff from central business districts are quite limited as opposed to other land use categories investigated by NURP. The data do suggest, however, that some sites may produce pollutant concentrations in runoff that are significantly higher than those from other sites in a given urban area. When combined with their typically high degrees of imperviousness, the pollutant loads from central business districts can be quite high indeed. The opportunities for control in central business districts are quite limited, however.

### Physical Effects

Several projects concluded that the physical impacts of urban runoff upon receiving waters have received too little attention and, in some cases, are more important determinants of beneficial use attainment than chemical pollutants. This contention requires much more detailed documentation.

### Synergy

NURP did not evaluate the synergistic effects that might result from pollutant concentrations experienced in stormwater runoff, in association with pH and temperature ranges that occur in the receiving waters. This type of investigation might reveal that control of a specific parameter, such as pH, would adequately reduce an adverse synergistic effect caused by the presence of other pollutants in combination and be the most cost effective solution. Further investigations should include this issue.

### Opportunities for Control

Based upon the results of NURP's evaluation of the performance of urban runoff controls, opportunities for significant control of urban runoff quality are much greater for newly developing areas. Institutional considerations and availability of space are the key factors. Guidance on this issue in a form useful to States and urban planning authorities should be prepared and issued.

### Wet Weather Water Quality Standards

The NURP experience suggests that EPA should evaluate the possible need to develop "wet weather" standards, criteria, or modifications to ambient criteria to reflect differences in impact due to the intermittent, short duration exposures characteristic of urban runoff and other nonpoint source discharges.

### Coliform Bacteria

The appropriateness of using coliform bacteria as indicator organisms for human health risk where the source is exclusively urban runoff warrants further investigation.

## Wetlands

The use of wetlands as a control measure is of great interest in many areas, but the necessary information on design performance relationships required before cost effective applications can be considered has not been adequately documented. The environmental impacts of such use upon wetlands is a critical issue which, at present, has been addressed marginally, if at all.

## Swales

The use of grass swales was suggested by two NURP projects to represent a very promising control opportunity. However, their performance is very dependent upon design features about which information is lacking. Further work to address this deficiency and appropriate maintenance practices appears warranted.

## Illicit Connections

A number of the NURP projects identified what appeared to be illicit connections of sanitary discharges to stormwater sewer systems, resulting in high bacterial counts and dangers to public health. The costs and complications of locating and eliminating such connections may pose a substantial problem in urban areas, but the opportunities for dramatic improvement in the quality of urban stormwater discharges certainly exist where this can be accomplished. Although not emphasized in the NURP effort, other than to assure that the selected monitoring sites were free from sanitary sewage contamination, this BMP is clearly a desirable one to pursue.

## Erosion Controls

NURP did not consider conventional erosion control measures because the information base concerning them was considered to be adequate. They are effective, and their use should be encouraged.

## Combined Sewer Overflows

In order to address urban runoff from separate storm sewers, NURP avoided any sites where combined sewers existed. However, in view of their relative levels of contamination, priority should be given to control of combined sewer overflows.

## Implementation Guidance

The NURP studies have greatly increased our knowledge of the characteristics of urban runoff, its effects upon designated uses, and of the performance efficiencies of selected control measures. They have also confirmed earlier impressions that some States and local communities have actually begun to develop and implement stormwater management programs incorporating water quality objectives. However, such management initiatives are, at present, scattered and localized. The experience gained from such efforts is both needed and sought after by many other States and localities. Documentation, evaluation, refinement and transfer of management and financing mechanisms/ arrangements, of simple and reliable problem assessment methodologies, and of implementation guidance which can be used by planners and officials at the State and local level are urgently needed as is a forum for the sharing of experiences by those already involved, both among themselves and with those who are about to address nonpoint source issues.



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